Protected cultivation in the Mediterranean climate

FAO
PLANT
PRODUCTION
AND PROTECTION
PAPER

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AND
AGRICULTURE
ORGANIZATION
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UNITED NATIONS

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A manual prepared by the horticultural
crops group of the FAO Plant Production
and Protection Division

FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
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FOREWORD

This Manual deals with intensive and specialized horticultural crop production techniques under protective structures.

The subject has been limited to a particular climatological environment defined as the mediterranean climate which is further described in Chapter II according to specific meteorological parameters. The mediterranean climate mainly prevails in countries surrounding the Mediterranean Sea, but also occurs in other regions and continents.

Horticulturists refer to the mediterranean climate when warm season species can be grown all the year round, by using only simple and economic environment control technologies for heating, ventilation and cooling, thereby eliminating the necessity for sophisticated temperature and humidity control systems within the greenhouse.

The paper is intended to enhance technological progress and to promote intensive horticultural crop production under protected cultivation. It contains up to date technical information and guidance for improving the productivity, quality and profitability of intensive greenhouse crop cultivation.

The document is expected to become a useful tool in the process of upgrading the scientific capabilities of training officers and extension agents, by providing them with useful reference material in support of their continuous endeavours in the transfer of know-how to the growers.

The members of the Working Group, listed in the Annex, have agreed to join forces in support of intercountry collaboration for the exchange of technical information, by providing their scientific and voluntary contributions for the publication of this document. They are prepared to further participate in promoting regional cooperation for the development of protected cultivation in the mediterranean climate.

L. Brader
Director
Plant Production and Protection Division

This One
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The paper has been prepared by the Horticultural Crops Group of the Plant Production and Protection Division, on the basis of the scientific contribution made by the following members of an ad hoc Working Group who drafted the original version in French:

A. Nisen	Faculté des Sciences agronomiques de Gembloux, Belgium. **Scientific Advisor and Editor**
M. Grafiadellis	Agricultural Centre of Northern Greece, Thessaloniki, Greece.
R. Jimenez	Centro de Investigación y Desarollo Horticola, Almeria, Spain.
G. La Malfa	Istituto di Orticoltura e Floricoltura, Catania, Italy.
P.F. Martinez-Garcia	Instituto Valenciano de Investigaciónes Agrarias, Moncada, Valencia, Spain.
A. Monteiro	Instituto Superior de Agronomia, Lisboa, Portugal.
H. Verlodt	Institut National Agronomique, Tunis, Tunisia.
O. de Villele	Station de Bioclimatologie de l'INRA, Montfavet, France
C.H. von Zabeltitz	Institüt für Technik in Gartenbau der Universität Hannover, Hannover, Federal Republic of Germany
I. Cl. Denis	Associate Professional Officer, Plant Production and Protection Division, FAO, Rome.
W.O. Baudoin	Horticultural Crops Production Specialist, Plant Production and Protection Division, FAO, Rome. **(Working Group Coordinator)**

Orientative technical guidance was provided to the Working Group by U.G. **Menini**, Senior Officer of the Horticultural Crops Group of the Plant Production and Protection Division.

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CHAPTER 1

INTRODUCTION

1.1 WHY GREENHOUSES IN THE MEDITERRANEAN REGION ?

It may be of interest to consider the real reasons that underlie the rapid growth of protected cultivation in a region (the Mediterranean area) which - up to 1960 - had nearly discarded a technique that performed particularly well in regions located further north.

First and foremost, the coming on to the market of materials ("plastics") that were experimented on in various climates before they proved ideally suitable for the socio-economic and climatic conditions of the Mediterranean region and whose properties can be adjusted or even created to suit specific local requirements.

The second reason is that, basically, the Mediterranean climate seems - a posteriori - particularly suited to benefit from the techniques of protected cultivation.

The layman might wonder - and he would be right to do so - why the Mediterranean region (Africa and Asia included) is largely adopting a fairly precise technique demanding investments at first sight seemingly uneconomic when the intensification of cultivation in developing countries supposes almost exclusively the rational application of fertilizers, properly applied irrigation, the use of pesticides, etc.

In fact the horticulturist tries - through his greenhouse - to modify the local climate, to make it meet more closely the needs of the plants which he wishes to grow (mainly tomato, pepper, ...) at any time of the year.

IN WINTER, it is the generated greenhouse effect that seems to be the prime justification for shelters: for a period extending from a few weeks up to a few months depending on the situation, the night temperature limits the active cultivation of heat-requiring plants, interrupts production and leads to unevenness in quality.

IN SUMMER, the role of the greenhouse looks more complex : although the shelter considerably reduces the incident radiation, which can often be excessive (**shading effect**), the temperature in the greenhouses can hardly be kept within limits acceptable to plants : for the time being, this is one of the limitations of the technique. However, the windbreak effect is worth mentioning as it acts - above all in arid zones - on two levels: it reduces the mechanical effect of the wind and it improves the hygrometric conditions within greenhouses.

"The shelter acts as a **reducer of the evapotranspiration** of plants : in a greenhouse this reaches some 70% of that recorded outside for a winter crop, whereas water consumption per kilo of fruit may be halved (e.g. tomato crop"(*). This phenomenon is due to the decrease in PET which also generates a better yield inside the greenhouse than outside.

When arid zones are submitted to dry warm wind, i.e. Chergui in Morocco, Sirocco in Algeria, Khamsin in Egypt, "the shelters are closed and the evaporation of the vegetable cover causes the relative humidity within the greenhouse to increase quite considerably and the temperature to rise slightly if at all (**cooling effect**). The harmful effect of chergui (high temperature, dry air) is reduced appreciably" (*).

When such conditions prevail (dry warm wind), the reduction in PET and, consequently, in the water requirement of the plants, is even greater than in normal conditions.

In his conclusions, the same author attributes an "oasis" effect to the greenhouse in arid or semi-arid regions : a decrease in light intensity, an increase in minimum temperatures and a reduction in PET.

The chief role of greenhouses in the Mediterranean region varies with the climate; it is either to improve the temperature conditions necessary for 'out of season' crop production (in this, it seeks to intensify production by lengthening the period of intensive cultivation) or to allow better use of the water available, this effect being far from negligible and likely to improve yields quite considerably.

(*) M. SIRJACOBS : "Intensification de l'agriculture en région aride par les cultures sous abris". Journées d'Etudes "Développement", Gembloux - Octobre 1985

1.2 CURRENT DEVELOPMENT OF PROTECTED CULTIVATION IN THE MEDITERRANEAN COUNTRIES

A complete and correct impression of the current development of protected cultivation in the Mediterranean region (i.e. in the countries enjoying a "Mediterranean climate") is rather difficult to form; official statistics are not always available, and the criteria adopted in different countries to identify protected cultivation often vary considerably. The figures generally include cultivation in greenhouses and in 'walk-in' tunnels as well as crops grown in low tunnels or in more simple shelters. Little information is available concerning the areas covered with plastic mulch.

1.2.1 AREA OF PROTECTED CULTIVATION

It appears, from the data supplied by researchers in the various countries, that an estimated 66 000 ha are devoted to greenhouse and walk-in tunnel cultivation (table 1), 58 500 ha of which being used for vegetable crops and 7 500 ha for flower crops and related activities (propagation, etc.).

Table 1 Area of protected cultivation in greenhouses and walk-in tunnels in the Mediterranean area (vegetable and flower crops)

Country	Reference	Year of reference	Vegetable crops (ha)	Flowers and related crops	Total (ha)
Albania	–	–	–	–	–
Algeria	Ben Hamou F.	1984	3 600		3 600
Cyprus	Patsalos K.	1984	134	32	166
Egypt	Hosny K.	1984	126		126
France	De Villèle O.	1984	6 500	2 500	9 000
Greece	Grafiadellis M.	1984	3 000	200	3 200
Israel	Von Zabeltitz C.	1983	400		400
Italy	Ist. Centrale Stat.	1983	16 356	2891+300(1)	19 547
Jordan	Kamal A.	1983	347		347
Lebanon	Farah J.	1984	1 100		1 100
Libya	–	–	–	–	–
Morocco	Marrakchi A.	1984	1 550	50	1 600
Portugal	Monteiro A.	1984	1 000	150	1 150
Spain	Annuario Estadistica agraria	1983	14 236	1 350(2)	15 596
Syria	Kamal A.	1983	20		20(3)
Tunisia	Ben Khedher M.	1985	900		900
Turkey	Yelboga K.	1984	9 114		9 114(4)
Yugoslavia	–	–	–	–	–

(1) Estimate
(2) Data from Martinez, P.
(3) Greenhouses and low tunnels
(4) 1 042 ha under glass; 7 387 ha under plastic houses; 685 ha under walk-in tunnels.

In fact, these figures represent the actual area of crops rather than the true area of shelters, the latter being lower as some plots may be used twice within the same year. It should be added, however, that this procedure is not commonly practised.

The figures put forward for some simple shelters - widely spread throughout the Mediterranean region - are characterized by the same inaccuracy. A generally accepted estimate for the area under low tunnels is 57 000 ha (table 2). However, these figures exclude the mulched surfaces as well as the areas covered intermittently, e.g. the peach tree orchards in southern Italy, covered in order to hasten ripening, and the vineyards in the same region, covered in order to hasten or delay grape harvesting. These represent about 6 000 ha.

Table 2 Area of low tunnels in some countries of the Mediterranean region

Country	Reference	Year of reference	Main crops	Ha
Algeria	(Lefki)	1983		300*
Cyprus	Patsalos K.	1984	tomato, cucumber, strawberry	515
France	De Villèle O.	1984	bean, asparagus, melon, strawberry, lettuce	20 000
Greece	Grafiadellis M.	1984	melon, water-melon	5 300
Israel	-	-		4 000*
Italy	La Malfa G.	1984	water-melon, melon strawberry	16 000
Jordan	Kamal A.	1984		629
Lebanon	Farah J.	1984		70
Portugal	Monteiro A.	1984		400
Spain	Martinez G.	1984	melon, water-melon strawberry	6 000
Tunisia	Ben Khedher M.	1983	tomato, pepper, musk-melon, water-melon, cucumber, squash	1 056
Turkey	Yelboga K.	1984	tomato, pepper, eggplant cucumber	2 486
Total				56 756

* Estimated

In the Mediterranean region, protected cultivation is practically synonymous with cultivation under plastic. Indeed, if mulches and simple shelters are not always plastic-based, greenhouses, on the other hand, are nearly exclusively covered with plastic.

The availability of plastics and the low cost of frame materials (generally wood) have largely contributed to the rapid development of protected cultivation in the Mediterranean region. In the 25 years of existence of cultivation under plastics, the area of greenhouses and walk-in tunnels area has increased by more than 2 000 ha per year.

Glass-covered houses (glasshouses) are losing ground and survive only - with certain exceptions - in the South of France and the North of Italy.

Protected cultivation is not evenly distributed throughout the countries that have adopted it. Generally, the southern regions are more involved than the northern ones, especially with regard to vegetable production. In Italy, 60% of the total area of protected cropping is located in the southern region and in Sicily; in Spain, plastic houses are to be found mainly along the southern coast (Almeria); in France, the centre of vegetable production is the Provence region; in Greece, 50% of the production originates from Crete, and in Portugal a similar proportion is to be attributed to the Algarve region.

Such a geographic concentration is obviously dictated by the feasibility of winter cultivation in cold houses. Indeed, heating is rare and limited to certain particular crops and areas.

1.2.2 UTILIZATION OF THE SHELTERS

Low tunnels are used for the cultivation of small-volumed vegetables (lettuce, strawberry, melon, water-melon, ...); they are also used for the initial growing stage of taller species (tomato, pepper ...).

Greenhouses and walk-in tunnels are mainly destined for the cultivation of vegetables; flower crops occupy only 11% of the total area.

Floriculture is not established in many countries and, where there has been a desire to turn to flower production in recent years, the lack of technology and of knowledge of the flower market have often been serious obstacles.

Italy, Spain and France are the three leading countries in the production of cut flowers and ornamentals. Together they produce 6 to 7 000 million units.

The annual production of vegetables in protected cultivation can be put at 5 million tons, 3 million of which come from low tunnels and other means.

These figures show the importance of this cultural method and also the vital role of marketing.

1.2.3 DISTRIBUTION OF SPECIES

1.2.3.1 Vegetables

Spain and Italy, the two countries most involved in protected cultivation (table 3), are perfect examples of the uneven distribution of species. Italy, for example, produces 24 different species in greenhouses and walk-in tunnels but 5 of them account for over 80% of the total output : tomato (29.5%), strawberry (18.5%), sweet pepper (17.7%), summer squash (8.5%) and egg-plant (7.6%). Whereas in Spain - all production methods considered together melon, water-melon, tomato and pepper are the most important crops.

Not only in Italy does the tomato rank first. It does so also in Greece, Tunisia and Morocco. Cucumber is also high on the list in some countries (e.g. in Greece, Turkey, Lebanon, ...), but the total production of all the Mediterranean countries together gives the following classification:

- First of all, **tomato**, 2 M. tons, or 35-40% of the total;
- Then, sweet and hot **peppers**: 0.6 to 0.7 M. tons or 15%;
- Followed by **cucurbits** (cucumber, melon, water-melon);
- Lastly, **strawberry**.

Table 3 Area and production of vegetable crops under protected cultivation in two Mediterranean countries mainly involved in these crops.

Crops	ITALY (a)				SPAIN (b)			
	Area (ha)	%	Production (T)	%	Area (ha)	%	Production (T)	%
Tomato	4 828	29.5	344 400	47.0	6 477	16.6	533 705	32.1
Strawberry	2 974	18.2	56 000	7.6	2 264	5.8	67 694	4.1
Pepper	2 898	17.7	109 500	14.9	5 514	14.1	254 195	15.3
Squash	1 386	8.5	58 390	8.0	1 092	2.8	52 744	3.2
Egg-plant	1 250	7.6	62 680	8.5	840	2.1	39.000	2.4
Cucumber	583	3.6	30 700	4.2	2 138	5.5	193 860	11.6
Lettuce	357	2.2	8 950	1.2	129	0.3	3 612	0.2
Melon + Water-melon	555	3.4	19 250	2.6	13 932	35.6	430 295	25.8
Others	1 525	9.3	43.908	6.0	6 746	17.2	88 619	5.3
Total	16 356	100%	733 778	100%	39 132	100%	1 664 624	100%

(a) greenhouses and walk-in tunnels.
(b) greenhouses, walk-in tunnels, low tunnels and mulching.

1.2.3.2 Flowers

The cultivation of flowers is strictly limited to the most typical Mediterranean region, and even there only a few of the numerous existing species are grown. This phenomenon is easily understandable since the houses are seldom heated and, therefore, success can only be achieved with, and profit can only be expected from, plants that are not over-demanding and that can be picked in winter and early spring. Carnation is the most popular flower crop, followed by gladiolus, lilium, gerbera and strelitzia. The pattern for Italy (table 4) is statistically representative of the cut flower production in the Mediterranean region. There, carnation and rose occupy respectively 45 and 16% of the covered area and represent 69 and 9% of the total production.

Table 4 Area (ha) and production (in 1000 flowers) of cut flower crops in protected cultivation in a Mediterranean country (Italy, 1983).

Crops	Area		Production	
	(ha)	%	(1000Fl)	%
Carnation	1 290	44.6	1 772 448	69.4
Rose	461	15.9	226 501	8.9
Asparagus	80	2.8	57 260	2.2
Gladiolus	286	9.9	76 834	3.0
Chrysanthemum	179	6.2	164 982	6.5
Strelitzia	91	3.2	11 893	0.5
Others	504	17.4	243 742	9.5
Total	2 891	100	2 553 660	100

Cultivation period

The cultivation periods - at least as far as vegetable crops are concerned - are quite flexible, and the choice is dictated by economic motivation rather than by agronomic factors. This is particularly true for tomato, egg-plant and pepper, which are more adaptable to different cycles than other crops. In the southernmost areas, these vegetables are planted in Autumn, in Winter, and in Spring.

As a result, harvesting itself extends over a long period. The first vegetables are picked in October and the last in June, and it is not unusual for the same crop to be harvested throughout the whole period. In any event, whatever the species, part of the production always reaches maturity between October and March.

For instance, during that period, unheated houses in the soutern latitudes of Italy produce over 40% of the total volume of squash, 25% of that of pepper, 30% of that of egg-plant and 10% of that of strawberry.

Spain records still higher percentages for tomato and pepper. This also applies to Morocco and Tunisia for tomato only. In the last two countries, the first fruits of a winter crop of water-melon may also ripen over that period.

Summer time is normally a dead season for protected cultivation in the Mediterranean region. Indeed, from July to September the environmental conditions within greenhouses hinder the normal biological activity of plants, and reversing the situation would require tremendous efforts of climatic control which would not necessarily return the expected profit nor even offset the additional expenses incurred.

Moreover, at this time of the year, competition from open-air vegetables, which "breaks" prices, is keen. Consequently, shelters in the Mediterranean area have to be written off in 6 or 8 months instead of in 12 as they are in northern European countries. This partly explains why investment/m² is to be limited at a much lower level.

This discontinuity sets the basis for the cropping system, for the number of crops and for their succession. Monoculture prevails, although two cycles remain possible provided that the first crop is planted very early in the Autumn.

N.B. The area cultivated under plastic mulch in the Mediterranean region is very difficult to estimate because :

- mulching is commonly practised under shelters (walk-in tunnels and even small shelters);
- this technique is frequently seen in more northern climates (e.g. France); (cf. § 3.3);
- the figures published do not distinguish between small shelters, unsupported plastics and mulch.

However, the total area under plastic mulch in the Mediterranean region can be roughly estimated at about 40 000 ha.

CHAPTER 2

PRODUCTION CONDITIONS

2.1 CLIMATE

The concentration of rainfall over the cold season is the only criterion recognized unanimously by climatologists as a feature of the Mediterranean climate. Considering that the only way to meet the water requirements of protected cultivation is efficient irrigation, this climatic characteristic is not sufficient in itself to indicate that the region is destined for protected cultivation. On the contrary, it foretells the difficulties involved in the utilization of shelters during the warm season of the year. Indeed, limited rainfall in Summer corresponds necessarily to high insolation which, in the Mediterranean region, causes almost uncontrollable temperature increases inside greenhouses.

Some climatologists associate a thermal characteristic "**mild winters**" with the rainy conditions of the Mediterranean climate. Stated simply, this feature cannot be turned into a generalization. Indeed, there exist a number of thermal variants of the Mediterranean climate and not all of them are favourable to a protected cultivation which tends primarily to develop "counter season" production.

2.1.1 CLIMATIC REQUIREMENTS OF PLANTS

To appreciate how interesting a given situation may be, its climatic characteristics must be analysed with respect to the requirements of the crops intended to be grown.

- The species grown under protected cultivation are mainly "**warm season**" species adapted to average monthly air temperatures ranging from 17 to 27°C., which roughly correspond to the following limits:

  - monthly average minimum temperatures : 12°C
  - monthly average maximum temperatures : 32°C.

- These species are **destroyed by frost**. It is generally accepted that the risks of sub zero air temperatures occurring for a period long enough to destroy the crops can be neglected when the monthly average minimum temperature exceeds 7°C.

- Although **temperatures remaining below 10 to 12°C** for several consecutive days are not likely to destroy crops, they affect their behaviour and impair productivity both qualitatively and quantitatively. However, **temperatures above 30°C** (if air humidity is very low) or above 30 to 35°C (in this case if the RH is high) are not easily tolerated by plants and cause extensive damage to crops.

- Crops require a certain **amplitude of daily variation of temperature** to allow normal physiological functioning: the minimum difference between day and night average temperatures is about 5 to 7°C.

- Whether possible **photoperiodic requirements**, linked to the duration of the night rather than that of the day, are to be met or not essentially depends on the time of year and on the latitude at which the plants are grown. When necessary the duration of night can easily be modified either by means of shading to lengthen it or by intermittent lighting to shorten it.

- In any event, whether the species are day-neutral or belong to a group whose photoperiodic requirements have been met, **the growth** is not normal until they have received **a number of hours of insolation**, probably corresponding to a **trophic threshold**. This threshold is roughly 6 hours a day, which - for the three months when days are shortest : November, December, January - corresponds to a **minimum 500 to 550 hours of insolation**. In terms of energy, such insolation corresponds to a global solar radiation of about 200 $\text{cal.cm}^{-2}.\text{d}^{-1}$ or 2 350 W.h. m^{-2} for a day (c.f. § 4.2. "Light" for another approach to this estimate).

- Even though the **hygrometric requirements** of crops are not easy to specify, it is commonplace to say that the extreme values of atmospheric humidity are unfavourable. Relative humidities of 70 to 90% can be regarded as being within a safe range.

- It is important to bear in mind that, even if not a classical climatological datum, **soil temperature** appears to be a determinant environmental factor; it seems that a threshold value (min. soil T°) could be fixed at around 15°C.

2.1.2 CLIMATIC CONTROL

Over the ages, growers have developed **ways of altering the environmental conditions** for their crops with a view to hastening earliness and improving the quality of production. A wide range of controlled environments is possible: from the mere choice of a sunny exposure, sheltered from the wind, up to the manufacture of fully air-conditioned units, possibly equipped with artificial lighting. The choice of controlled environments is obviously limited by the level of capital investment and operating costs that the user is ready to bear.

Attempts to hasten earliness - a major concern - necessarily include research for obtaining maximum lighting and for increasing air and ground temperatures.

Concerning the **search for maximum lighting**, it may be observed that the quantities of energy that any move to correct the deficiencies of winter insolation would involve are such that they exclude any possibility of creating artificial lighting likely to bring about a significant increase in photosynthesis. Practically speaking, the level of satisfaction of light requirements is fixed by the natural climate.

Table 5 Global (real) solar radiation observed in different parts of the Mediterranean area (in Cal.cm^{-2}.d-1(A) and W.h.m^{-2} d-1(B)

			December		March		June		September	
			A	B	A	B	A	B	A	B
Casablanca	(Morocco)	34°N	200	2 320	375	4 350	550	6 400	450	5 225
Ierapetra	(Greece)	35°	205	2 380	385	4 450	685	7 950	520	6 050
Monastir	(Tunisia)	36°	190	2 205	345	4 000	570	6 600	410	4 750
Almeria	(Spain)	37°	200	2 320	380	4 400	635	7 375	455	5 275
Gela	(Italy)	37°	185	2 145	370	4 300	620	7 200	465	5 400
Toulon	(France)	43°	140	1 625	350	4 050	625	7 250	420	4 875
Brussels	(Belgium)	51°	35	405	205	2 375	460	5 350	215	2 500

To provide plants with maximum lighting means keeping crops out of shade and – when shelters are to be used – choosing high transmittance covering materials and designing the greenhouse rationally (shape and orientation). Compared to E-W-orientated shelters, N-S ones do not appear to bring about notable delays in earliness in the Mediterranean region, but the better distribution of light in the latter type of shelter leads to greater uniformity in crop growth (cf. § 4.2).

- There are various ways of improving the soil and air temperatures:

1. **Windbreaks** (cf. § 3.4.1)

Even where winds are neither violent nor frequent, windbreaks decrease the average level of turbulence quite significantly, thereby favouring:

- the production of quality crops as a result of the limitation of mechanical damage
- earliness due to a slight increase in the average air temperature (about 1°C).

However, it must be kept in mind that any reduction in turbulence increases the diurnal variation of temperature. Consequently, in periods of frost, the risks of damage are aggravated since the minimum temperatures are reduced (at ground level the temperature can be lowered by nearly 1 or 2°C).

2. Mulching (cf. § 3.3)

Plastic mulching is used for various purposes: microclimatic modifications near the ground, weed control or phytosanitary concern aimed at keeping plants off the ground. Mulching acts mainly on the ground temperatures, raising them by 1 to 5°C according to the nature of the film and the way it has been laid down. On the other hand, mulching hardly affects air temperatures, even at ground level.

3. Semi-forcing tunnels (cf. § 3.2) (= low tunnels)

Semi-forcing tunnels are used for short periods in order to help crops start faster at a time when temperatures are too low. Furthermore, they are quite often associated with mulching. The cumulative effects of these two techniques raise ground and air temperatures by 5 to 10°C during daytime. As soon as solar radiation intensifies, the air temperature under the tunnel becomes excessive and ventilation becomes necessary; it can be achieved through perforations or by rolling up the film. In contrast, during the night, the temperatures undergo relatively slight changes.

4. Greenhouses and shelters (c.f. § 3.1)

Made up of transparent materials supported by various types of structures, greenhouses and shelters are enclosures within which a climate is created that differs from that outside. This modification of the physical environment of crops is linked:

- on the one hand, to the property specific to each covering material to "trap" radiant energy inside the enclosure (glasshouse effect);
- on the other hand, to the limitation of turbulence. As in the case of semi-forcing tunnels, **night temperatures** are only slightly affected : warming up does not exceed 2 to 5°C. When the sky is clear and air humidity low, **"temperature inversions"** may occur at night : it is then colder under shelters than outside. If the greenhouse is not equipped with heating, ventilation will help to limit cooling. In contrast, **during daytime**, the greater the solar radiation and the lighter the wind, the greater are the gains in temperature.

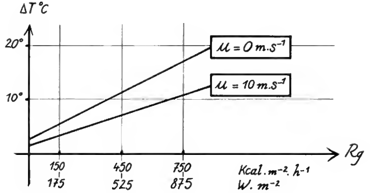

Fig. 1: Increases in temperature (ΔT) in a closed, properly irrigated greenhouse in relation to the intensity of solar radiation (Rg) and wind speed (μ). Results based on a mathematical model.*

Thus, the gains in temperature are linked to latitude and, for a given situation, to the time of year. In December some 10°C are easily gained in greenhouses whilst, from March onwards, temperature rises reaching 15 to 20°C may prove difficult to control by means of free ventilation alone.

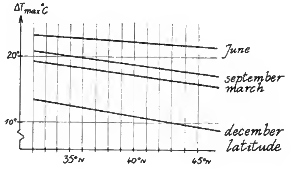

Fig. 2: Maximum amplitude (ΔTmax) of temperature rises within a closed, properly irrigated greenhouse at various times of year and for various latitudes.

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* CHIAPALE J.P. et al (1984) : "Estimation of Ventilation Requirements of a Plastic Greenhouse" ACTA HORTICULTURAE 154, 257-266 (Plastics in Mediterranean Region - Hammamet).

a. **Heating** (cf. § 4.1.1)

In some regions, earliness cannot possibly be achieved without heating, either occasionally or systematically. It must be recognized that, in the Mediterranean climate, all the conditions favouring heat loss in greenhouses may occur together: lowering of the outside temperature, clear sky, dry air, strong wind. Even though these circumstances are exceptional, it is advisable to install boilers as powerful as those recommended for more northerly regions.

Table 6 Commonly installed power and actual energy requirements for a given rise in temperature(*) (for a single-cover greenhouse)

Gain in T° (inside - outside T)	Normally installed power for the boiler		Actual energy requirements	
	k.cal $m^{-2}.h^{-1}$	$W.m^{-2}$	k.cal $m^{-2}.h^{-1}$	$W.m^{-2}$
5° C	100	115	45	50
10° C	150	175	90	105
20° C	250	290	180	210

(*) CHIAPALE, J.P. et al. (1980): "Regional estimation of heating requirements of greenhouses" - ACTA HORTICULTURAE 115, 443-502 (Energy in protected cultivation).

For a given production regime, the period for which heat is required will, of course, differ appreciably according to the average climatic conditions, and will be shorter in Mediterranean regions than further north.

b. **Ventilation** (cf. § 3.1.2)

Air change in the greenhouse either by means of free ventilation (openings) or by forced ventilation (fans), remains the classical way to control excessive air temperatures inside a shelter. Ventilation requirements, expressed in volume of air renewed per hour, vary with the intensity of solar radiation and with the acceptable level of temperature rise within the house.

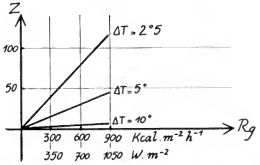

Fig. 3: Estimate of the volume of air renewed per hour (z) within a properly irrigated greenhouse in order to keep air warming at a given value ΔT in relation to the intensity of solar radiation

If the maximum values of local solar radiation are known, it is possible to form an image of how efficient various ventilation techniques are.

Table 7 Approximate values of maximum global solar radiation intensity depending on latitude (at 12.00 solar time) - Q max: kcal.m^{-2}.h^{-1}(A) or W.m^{-2} (B)

Latitude	December		March		June		September	
	A	B	A	B	A	B	A	B
32° N	470	550	735	855	905	1 050	790	915
38° N	390	455	670	780	885	1 025	730	845
44° N	305	355	590	685	855	995	665	770

If only **natural ventilation** occurs (wind speed 5-8 m sec $^{-1}$) and, even if the efficiency of openings is maximal, it seems that the air exchange figure cannot be more than 40 or 50 changes per hour. As a result, **in March**, the temperature rise inside the greenhouse cannot be kept below 5°C (difference between inside and outside air T°) and, **in Summer**, it will range around 10°C.

2.1.3 CLIMATIC SUITABILITY

From the simplifying hypotheses previously put forward concerning the requirements of crops and the possibilities for environmental control it must be kept in mind that the **warm season species**, which might justify the use of "out of season" cultivation techniques, have as major requirements:

- **solar radiation** corresponding to a minimum energy contribution of 200 cal. cm^{-2} .d^{-1} (2 350 wh.m^{-2} .d^{-1});
- **Average monthly air temperatures** ranging, in the coastal regions, from 17° to 27°C or, inland, from 17° to 22°C. (This distinction is due to the fact that, inland, mainly in summer, the amplitude of the range of temperatures is much higher than along the coast: 20°C instead of 10°C). If the temperature is held to be excessive from 32°C onwards, the average temperature limits are 27° and 22°C depending on the location;
- **A soil temperature** of at least 25°C.

From an economic point of view, environmental control cannot possibly offset a possible lack of solar radiation. Indeed only the limits of thermal requirements can be changed.

Taking into account only the possibilities offered by cultivation under plastic shelters and **excluding any use of air-conditioning** (heating, forced ventilation), it may be assessed that minimum temperatures will remain almost unchanged whilst the maximum temperatures will be raised by about 10°C, since well-designed free ventilation makes it possible to confine the daytime temperature rise to that level. Environmental control thus makes it possible to increase the average temperatures by 5°C and hence to increase by the same amount the climatic limits of suitability for the cultivation of warm season species:

in the coastal region	$12^\circ \leqslant \overline{T^\circ} \leqslant 22^\circ C$
inland	$12^\circ \leqslant \overline{T^\circ} \leqslant 17^\circ C$

Beyond these limits, some form of air conditioning will have to be used: heating, forced ventilation or even evaporative cooling, techniques which suppose that the horticulturist has electricity at his disposal and which involve expenditure which may not be economically justified. Graphs based on average monthly air temperatures and global solar radiation (cf. Figs. 4 to 8) readily provide an indication of the climatic suitability of a region for the cultivation of warm season species.

N.B. In these figures, "air-conditioning" means artificial heating and cooling, including forced ventilation.

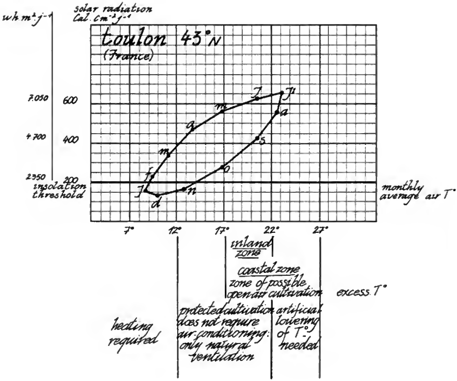

Fig. 4: Estimate of climatic suitability for the cultivation of warm species from the average monthly air temperature and from solar radiation : TOULON (France - 43°N)

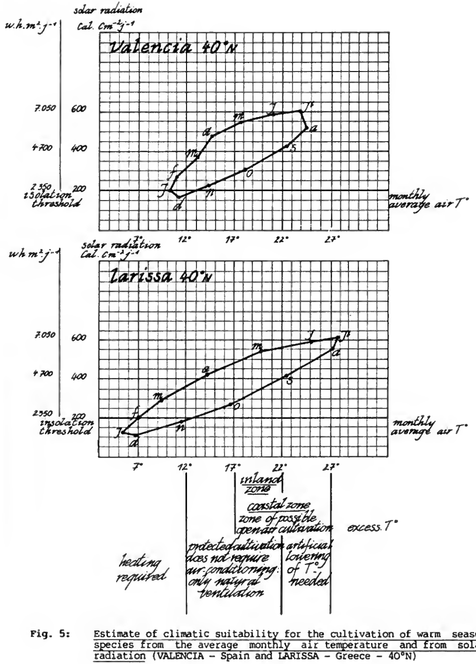

Fig. 5: Estimate of climatic suitability for the cultivation of warm season species from the average monthly air temperature and from solar radiation (VALENCIA - Spain and LARISSA - Greece - 40°N)

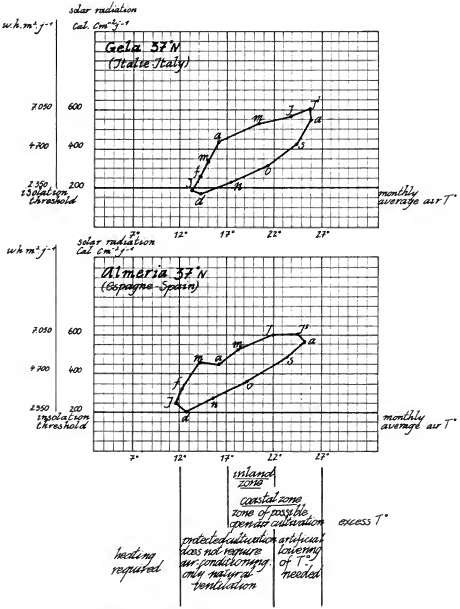

Fig. 6: Estimate of climatic suitability for the cultivation of warm season species from the average monthly air temperature and from solar radiation (GELA - Italy and ALMERIA - Spain/37°N)

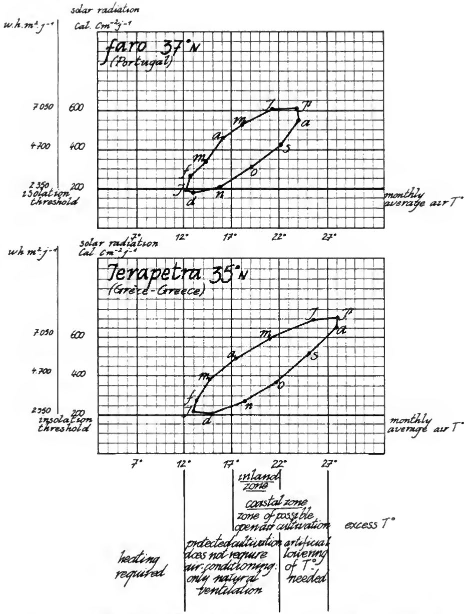

Fig. 7: Estimate of climatic suitability for the cultivation of warm season species from the average monthly air temperature and from solar radiation (FARO - Portugal - 37°N and IERAPETRA - Crete - 35°N)

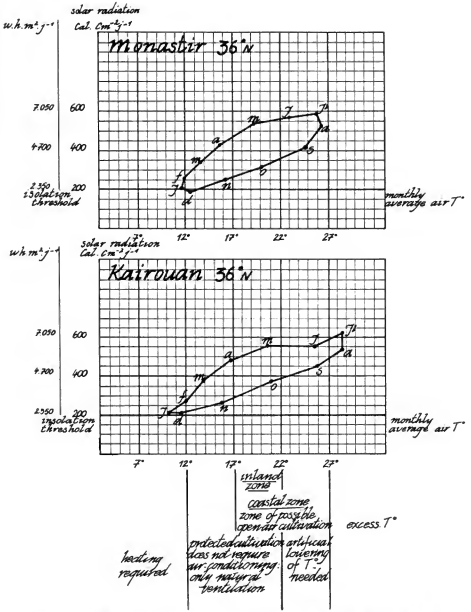

Fig. 8: Estimate of climatic suitability for the cultivation of warm season species from the average air temperature and from solar radiation (MONASTIR and KAIROUAN - Tunisia/36°N)

A survey of the climatic data relating to many places in countries bordering the Mediterranean leads to the following general conclusions :

1. Because of unduly low temperatures in winter, there is nowhere in the Mediterranean region with a climatic situation which allows all-the-year-round open-air cultivation of the so-called warm season species.

2. The minimum insolation requirements of these crops, which correspond fairly well to 500 hours' insolation in November-December-January, are met only south of the 35th parallel and in the extreme south of the Iberian peninsula.

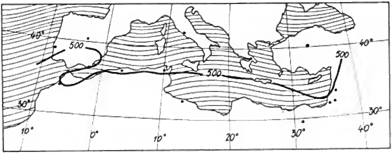

Fig. 9: Limit of the zone where the requirements for winter insolation are met with 500 hours' insolation in November, December, January.

3. In the absence of heating, protected cultivation satisfies the thermal requirements of warm season species only in the coastal regions south of the 35th parallel.

4. Forced ventilation of greenhouses and shelters is essential during the summer period throughout the Mediterranean area. If not used, crop production is so heavily affected - both in quantity and quality - that it often leaves no option but to cease all cultivation.

5. The advantages of the coastal locations vanish quite rapidly as one gets further away from the sea because of the increase in the amplitude of the temperature range. The decrease in minimum temperatures, and the rise in maximum temperatures, then make it necessary to use heating and forced ventilation.

From a practical point of view, with the exception of the south of the Iberian peninsula (i.e. Almeria, Malaga, Cadix, Faro), the 35th parallel marks the limit north of which the lack of winter insolation may more or less affect the development of warm season species.

Also, **north of this limit**, because of the cool winter weather, the only way of producing warm season species is by cultivation in heated greenhouses or shelters.

For tomatoes, for example, the persistence of a cloudy sky during the weeks around the winter solstice can inhibit the formation of the floral system or cause it to die. As a result, two months later, production comes to a temporary stop. On the contrary, for clusters, flowers and fruits normally formed at the end of October or the beginning of November, their development continues (more or less rapidly, depending on the conditions) and leads to production in late December/early January.

South of the 35th parallel, insolation and temperatures allow the winter cultivation of warm season species under unheated shelters only in coastal regions.

Throughout the Mediterranean region, greenhouses and shelters cease to be used in summer in the absence of forced ventilation because of excessive heating due to the intensive solar radiation.

Table 8 Climatic suitability for the cultivation of warm season species in the Mediterranean area

North of the 35th parallel	Winter	open-air cultivation is impossible; protected cultivation must be heated, and there is a risk of inadequate solar radiation
	Spring Summer	open-air cultivation is possible; protected cultivation must be ventilated
South of the 35th parallel (+ Almeria, Malaga, Cadix, Faro)	Winter	open-air cultivation is impossible; protected cultivation without heating is possible in the coastal regions
	Spring Summer	open-air cultivation is possible; protected cultivation must be ventilated

The use of heating or forced ventilation that the climatic conditions can impose often involves heavy investment. The power of the heating equipment, for example, is not much different from that adopted in countries located further north, because of an accumulation of the causes of energy losses: clear night skies, strong wind, important - if exceptional - cooling.

Air-conditioning (forced ventilation) is sometimes impracticable either on the grounds of cost or because of the absence of an electrical supply.

Therefore, in winter, the production schedule for warm season species has to be stopped and, in summer, the use of greenhouses and shelters must be discontinued.

Indeed, essentially for climatic reasons, repayment of the capital costs of greenhouses and shelters - and of the air-conditioning systems which may be associated with them - can be achieved only with highly profitable crops.

2.2 SOIL

The specificity of protected cultivation is such that a number of requirements must be taken into account before selecting the soil on which greenhouses and shelters are to be erected.

2.2.1 TEXTURE

The quantity of fertilizers applied, the frequently poor quality of the irrigation water or the after-effects of sterilization often lead to risks of salinity which force growers to leach the soil. Good permeability is, therefore, of paramount importance. This means that the soil should have a rather coarse texture : at least 50% of sand, about 30% of silt and 20% of clay. Small stones, even in large quantities, are beneficial from a physical point of view. Yet another advantage of such a texture is that the surface layers of the soil warm up quite rapidly.

2.2.2 DEPTH

The root system of most plants grown in protected cultivation does not go deeper than 30 to 40 cm. Consequently, this serves as an indication of the minimum depth required, with special care to avoid impeded drainage caused, for example, by continuous crusting or by the clay stratum underneath.

2.2.3 PHYSICO-CHEMICAL CHARACTERISTICS

- Most crops require a pH within the range 6 to 7.5

- In view of the rate at which organic material is mineralized in the Mediterranean climate, there is no need to look for well supplied soils. There seems no necessity either for massive and regular supplies of organic material, since the structure is sufficiently aggregated and aerated. Crop residues (roots and planting blocks) are a good source of organic matter.

- Since the mineral nutrition of plants is ensured by the application of fertilizers before and during the cultivation period, soils need not necessarily contain nutrients in large quantities. The initial nutrient status of a soil should, however, be determined:

Table 9 Initial nutrient status of two different soils

mg/kg content	rich soil	very poor soil
P_2O_5 available	250	50
K_2 (exchangeable)	400	80
Mg (exchangeable)	250	60

2.2.4 ENVIRONMENT

The final choice of where to erect greenhouses and shelters should not be taken until due consideration has been given to some features of the immediate environment.

- Exposure : since earliness and productivity require maximum insolation, SE or S exposure is quite advisable.

- Slope : very steep slopes, when exposed favourably, can yield early production but require terracing. However, the creation, care and equipment needed by such terraces represent a real financial and manpower burden.

- Rain water drainage: the intensity of rain storms in the Mediterranean region is such that drainage systems must be planned ahead to remove huge volumes of water (1 000 m^3/ha/h) (100 mm/h). Greenhouses should be built parallel to the general slope, and collecting ditches should be dug in between the units. The ditches dug to remove rain water should be supplemented by a network of drains to dewater the soil and thereby to facilitate periodical leaching (control of salinity.

- Protection against wind: naturally sheltered situations are, of course, a valuable asset. Nevertheless, absolute priority must be given to the search for maximum insolation.

- Shape of the site: the investments are so considerable that growers should look for the most suitable tracts of land, i.e. those which allow maximum utilization. This is offered by regular-shaped plots with boundaries parallel to the slope, to the direction of prevailing winds or to a north-south line.

2.3 WATER

In view of the huge volume of water needed for protected cultivation in the Mediterranean region as a result of insolation, the water resource has to be analysed with regard to three aspects : quality, quantity and availability.

2.3.1 QUALITY

Salinity is the feature which deserves the most serious attention because of the important losses in productivity that it may cause. The following table gives an idea of the impact of the quality of water on production, disregarding any risks of toxicity due to the presence of certain ions (Cl^-, Na^+, B, HCO_3) (see also §4.4).

Table 10 Reduction in production of some sensitive or tolerant crops in relation to the salinity of water used for irrigation

Quality of irrigation water		Yield reduction	
Dry matter g/l	Conductivity mmhos/cm	Sensitive species (bean,strawberry)	Tolerant species (tomato,cucumber)
0.5	0.5	- 5%	- 0%
1	1.5	- 25%	- 0%
1.5	2.3	- 50%	- 10%
2	3.0	- 65%	- 20%
3	4.5	- 100%	- 40%

The suspended solids content of water conditions the choice of filters and drippers to be used in micro-irrigation.

The temperature of the water must be known by the user so that he may define the types of irrigation system which are the least likely to cause damaging thermal shocks to crops. Excessively cold water can be stored and warmed in the greenhouse for a time before being used, while excessively warm water can be agitated or made to flow in the open air for awhile.

2.3.2 QUANTITY

Due to the likely leaching requirements, 2 mm/day in winter and 7 mm/day in summer seem a reasonable maximum consumption.

2.3.3 AVAILABILITY

Success in protected cultivation means that water must never be absent in the region of the root system for fear of creating water stress. (Automatic) trickle irrigation may greatly help to achieve this aim once water is supplied permanently. When water "turns" are imposed, temporary stocking should be arranged in order to ensure continuous supply of the irrigation network.

2.4 SOCIO-ECONOMIC FACTORS

2.4.1 TECHNICAL KNOWLEDGE

Protected cultivation is undoubtedly more difficult to manage than seasonal production or even than advanced production in the open air. Furthermore, the slightest mistake may involve dire economic consequences as a result of the massive investment undertaken. Growers must, therefore, acquire a sound technical knowledge and be backed up and advised by highly competent technicians willing to convey everyone's experience to everybody else in the group and to transmit the newly acquired knowledge.

Even the highest level of knowledge needs some kind of motivation, and profit-making remains the most powerful stimulant, being the only condition for horticulture to be given close attention.

2.4.2 AVAILABILITY OF MATERIALS

Protected cultivation relies upon a number of controlled environment techniques whose trustworthiness depends on the ability to remedy operating faults promptly. Whatever the material or equipment it must be in current use and distributed by a supplier keen to maintain a constant stock of spare parts.

Similarly, agricultural supplies (seeds, fertilizers, crop protection products) must be available on the local market at all times.

Protected cultivation has no time to waste over undue delays imposed by petty 'red-tape': purchasing licences, import licences, etc.

2.4.3 OUTLETS AND MARKETING

Whether protected cultivation focusses on the local market or on export, growers must be backed up by a "marketing service" involving packing, transport, etc. They are too busy to take time off to go to the market and to organize marketing.

2.4.4 SIZE OF PRODUCTION UNITS

The constant care demanded by crops excludes the possibility of oversized units. Beyond a certain limit, the grower is no longer efficient: smaller units headed by a single man seem more profitable enterprises, and though precise limits are difficult to fix, one can estimate that 2 ha represent a reasonable size.

2.4.5 CREDIT FACILITIES

Owing to the size of the investments required by protected cultivation, the grower must obviously be granted attractive terms of credit, both as to the amount allowed and to the interest asked.

N.B. It is essential to remember that:

- the sophistication of techniques has limits: indeed, the more complex the technique, the fewer horticulturists are likely to make the best use of it as it then requires more extensive basic knowledge;
- the climate and socio-economic conditions differ so much from country to country and even from region to region that the horticulturist can seldom content himself with imitating or "copying" the working methods devised only a stone's throw away from his own enterprise: he must adapt himself to the particular conditions of his region, and this is neither simple nor plain.

CHAPTER 3

STRUCTURES, MATERIAL AND PRODUCTION EQUIPMENT

3.1 GREENHOUSES AND WALK-IN TUNNELS

3.1.1 TYPES OF CONSTRUCTION FOR DIFFERENT MEDITERRANEAN AREAS

In the Mediterranean region, the total area under plastic-covered greenhouses is far larger than that under glass-covered ones.

The main problems facing greenhouses in that region are:

- winter temperatures falling below the biological minimum, therefore requiring heating for up to 3 months;
- quite high daytime temperatures even in spring, with insufficient ventilation for 4 to 6 months;
- high level of humidity at night;
- strong winds;
- water quality and water shortage;
- CO_2 shortage during the day in closed greenhouses.

If one considers plastic-covered greenhouses only, the following points are of importance:

- design and construction of the greenhouse;
- chemical composition and properties of the covering film;
- film fastening;
- stretching of the film over the structure;
- ventilation as part of the structure.

The design of the structure can help to solve the above mentioned problems. Indeed, the avoidance of leakage can prevent low night temperatures; sufficient ventilation can reduce daytime temperatures; shape, components, etc. can be studied to increase resistance to wind: gutters fixed to the roofs can usefully collect rainwater to offset water shortages.

Some of the existing plastic-covered greenhouses have disadvantages. The following can be mentioned:

- the erection of the structure and the changing of films involve high labour costs:
- the film loses tension due to solar radiation and to friction against the structure;
- the film is likely to flutter on the structure in the wind;
- water condensation reduces light transmission and causes dripping;
- ventilation is inadequate in multispan greenhouses;
- excessive volume of the greenhouse frame, especially when of wood, leads to low light transmission.

This leads to the conclusion that current plastic-covered greenhouses show poor qualities, and it would, therefore, be useful to define some minimum requirements.

Considering the problems and disadvantages, the requirements for plastic-film greenhouses can be defined as follows:

- low building and maintenance costs
- minimum standards against wind loads
- simple, low labour cost film replacement; disconnectible fastening devices integrated with the construction
- avoidance of film damage on the structure due to fluttering in the wind; use of simple stretch devices; tight stretching of the film
- avoidance of contact between the film and parts of the structure which are heated by solar radiation
- possibility of covering with either film or rigid plastic
- effective ventilation
- tightness of the construction; avoidance of leakages
- long-term durability of the film used, if summer ventilation is sufficiently effective
- increased light transmissivity of the film in the case of covering with double-layer film; higher light transmissivity of the construction
- avoidance of drip from water condensation by choice of the right roof slope, film treatment or new anti-drip films

- high side-walls and few structural elements within the house so as to allow mechanized cultivation.

A vast choice of structures and construction materials is to be found in the Mediterranean area, even under similar climate conditions. Traditional reasons can explain this. However, the price of the material is often decisive: wood is not always cheaper than steel or steel pipes.

Therefore one has to develop a basic construction which can be made both with wood and/or steel and which meets the demands imposed by the climatic conditions in the Mediterranean region. It is not the national traditions but the climatic conditions which are decisive for greenhouse construction!

A survey of the greenhouse structures currently used in the Mediterranean region for vegetable crops may prove useful before trying to describe a suitable type of construction.

The shapes that appear most frequently are: saddle-roof (a), shed-roof (b), round arch (c), round arch with vertical side-wall (d), pointed arch with sloping side-walls (e) and pointed arch with vertical side-walls (f).

Plastic films stretch more easily over curved roofs than over straight ones.

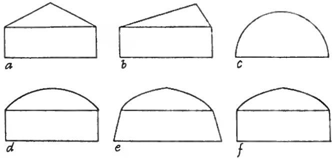

Fig. 10: Possible shapes of greenhouses

● In **PORTUGAL**, greenhouses cover an estimated 1 100 ha of ground with about 600 ha in the Algarve region. In the south, growers prefer the saddle-roof type made of cheap wood. The cheapest is eucalyptus. Used without any kind of treatment, this wood affords a "life expectation" of up to 4 years. The roof is made up of timbers 50 cm apart, with the film passing alternately above and below them.

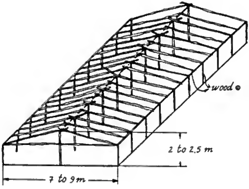

Fig. 11: Wooden structure from south Portugal

Firstly the lower timbers are assembled, then the film is stretched over the framework, and finally the upper timbers serve to fasten it all together. Fastening therefore does not require nailing, which is an advantage for the duration of the film.

There exists also a mixed type of construction : the posts are of pressure-treated pinewood and all the other parts are of eucalyptus-wood. However, a newer type has appeared that uses pressure-treated pinewood exclusively and which is expected to extend the life of the structure to 10-12 years.

Until recently, growers used to prefer single-span greenhouses with vents along the side-walls. This type provides efficient ventilation. Nowadays, however, they seem to turn to multispan structures as a result of their lower price. Ventilation should not, however, be disregarded. Indeed, for it to be sufficient through the side-walls, multispan greenhouses should not be over 20 to 25 m wide (cf. 3.1.2).

● The surface covered by plastic film greenhouses in the **Almeria** region of southern **SPAIN** can be put at more than 11,000 ha. Most structures are inexpensive. The "Parral" type shown in Fig. 12 is undoubtedly one of the most frequently met. The basic structure is made of wooden posts stuck vertically in individual concrete foundations and linked to each other by tension wires running across their tops. Outward facing buttresses give stability to the whole construction. The tension wires also serve as a support for the two nets in between which the film is sandwiched. The lower net is of wire (30 x 30 or 20 x 40 cm mesh) and the upper net of plastic cord (40 x 40 mesh). Once the film is inserted, the two nets are fastened to each other and to the tension wires by pieces of wire that go through the film and just need to be cut off when the latter gets old and needs replacing.

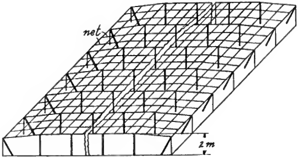

Fig. 12: The Almeria type "Parral" (Spain).

The aim of sandwiching the film between netting is to ensure stability in a region where wind speed is quite high.

To erect structures of this type, experts with good experience are necessary. The nets and the film must be stretched very correctly and carefully, otherwise the nets do not avoid fluttering in the wind. The possible fluttering and the contact between film and wire net are disadvantages of the construction and do not meet the requirements previously mentioned. The risk of damaging the film is higher than with other forms of construction. The greenhouse construction has either little or no roof slope. The construction has developed in relation to the conditions of rainfall (only 200 mm per year) in this region. If it is raining, growers cut holes in the film: the sandy soil, "enarenado", receives the water drops without any problem. Farmers prefer to have flat roofs because the construction cost is cheaper. For regions with higher rainfall, this form of construction is unsuitable.

The Parral-type can also be built up with metal posts. The minimum size of the wooden or metal Parral-type is 2 000 m².

These greenhouses, which are at least 30 to 40 m wide, are ventilated only through vents along the side-walls, causing ventilation towards the centre of the unit often to be inadequate (cf. 3.1.2).

Low cost is the only advantage of this system. However, better quality and higher yields are a must, and one of the factors that can help to achieve this is improved ventilation throughout the structure.

Other constructions, used in the Mediterranean region, having better interior climatic conditions and offering good resistance to wind can be built at similar costs.

- **FRANCE** has an estimated 6,000 ha of greenhouses, one third of which is under glass and the rest under plastic film. **TUNISIA** devotes 1,100 ha of its land to greenhouse cultivation, whilst about 2,000 ha are used for this purpose in **ALGERIA**, 1,600 ha in **MOROCCO** and 1,100 ha in **LEBANON**. The single span round arched type (cf. Fig. 13) is by far the most frequently met in these five countries.

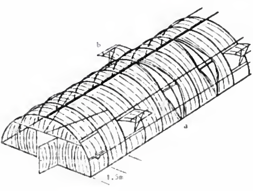

Fig. 13: Single span round arched greenhouse in southern France, Tunisia, Algeria, Morocco and Lebanon. (Ventilation through a or b openings)

This type of greenhouse offers sufficient stability against wind but is unsuitable as part of a multispan unit. Ventilation is provided through side vents (b), or through openings that become effective as the film is pulled aside (a). However, neither of these nor a combination of them is sufficient to ensure adequate ventilation, and various attempts are being made to improve the situation.

One possibility is to use fixed 6 m wide plastic film sheets in combination with removable 2 m wide ones. In this way the natural ventilation is considerably improved. On the same system, simple devices can be adapted to obtain a movable sheet for opening and closing. Both edges of the movable film sheet are fixed to a wire cable at 3 or 4 places (1 or 2 in the roof and 1 at each side). By means of a hand winch, both edges are moved to the centre of the movable film sheet.

In France, a new round arched greenhouse prototype has been developed with a ventilation opening along the top, Fig. 14. The greenhouse has two fixed side coverings and a movable double film mechanism in the top roof area. Opening and closing of the top vent is produced by a rolling mechanism, moving a main shaft on which the film is fixed parallel to the ridge. The advantage of this construction is the relatively high amount of 35% vent area compared with the greenhouse floor area (see 3.1.2). This system does not work on warm rainy days for plants that need protection from rain. The greenhouse can only be built as a single span house. Measurements of climate and yield gave good results. For moving the roof vent many cables, pulleys and other mechanisms are necessary, so that the costs, durability and maintenance are questionable. Half way between single and multispan greenhouses, the 2-span one proves definitely interesting both by its performance (in many Mediterranean regions) and by its price.

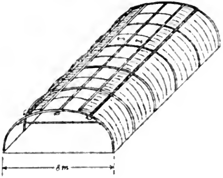

Fig. 14: Round arched greenhouse with roof ventilation from France.

• The total area under greenhouses in ITALY is about 17,000 ha, 15,000 ha of which are covered with plastic and 1,500 with glass. Sicily has about 5,500 ha of ground under plastic film greenhouses. The type prevailing in Sicily is the saddle-roof construction based on rectangular concrete or round wooden trusses (Fig. 15). The roof frame is made of wood and is often covered with a double film fixed to ledges running along the frame both inside and outside. The double-layer film is intended to reduce heat losses at night.

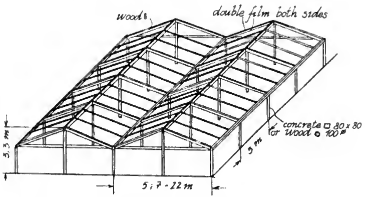

Fig. 15: Wooden structure for double film from Sicily.

In Salerno, they have the round-arched multispan type, with a very light frame, the film being stretched by "nylon" strings; this construction is very cheap and efficient.

• **GREECE** is covered by about 3,000 ha of greenhouses, only 40 ha being glass-covered. About 1,000 ha of the Isle of Crete are plastic-covered, but the majority of greenhouses are simple wood constructions provided with ventilation systems at the side-walls (Fig. 16). The film is nailed onto small ledges running along the wooden bars. The houses are very low and the climate in multispan houses is not adequate. Instead of a foundation the posts are dug 70 cm deep in the soil. The houses are relatively resistant to wind forces.

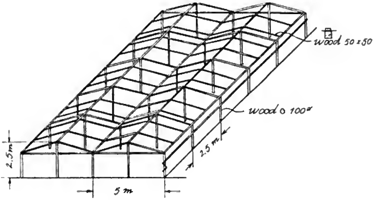

Fig. 16: Wooden structure from Crete.

Another type of construction to be found in Crete is one resulting from a combination of steel and wood (Fig. 17). The purlins are wooden beams and the bars steel pipes.

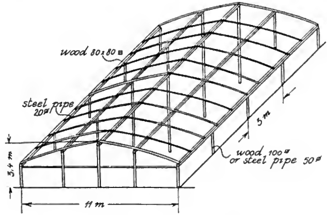

Fig. 17: Combination of wood and steel pipes. (Crete)

A similar construction exists in northern Greece (Fig. 18). The plastic film on the roof is fixed by rolling it around two pipes (b). Between the fixed ends of the film there are also two parallel pipes, one above and one below the film (a). No nails are necessary for fastening the film. Yet not every country can afford the expense of steel pipes (2 are needed per metre). In northern Greece, steel pipes are relatively cheap.

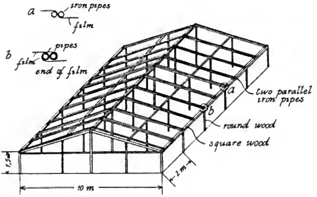

Fig. 18: Construction from northern Greece with two parallel pipes on the roof.

In northern Greece, the houses are provided with automatic side-wall ventilation systems. Single-span greenhouses are preferred in this region because of snowfalls. Spans are 10 to 11 m wide, which is a suitable size for efficient ventilation.

- About 160 ha of the Greek part of **CYPRUS** are covered with greenhouses, most of them being in the southeast region of Paralimni and in the southwest region of Paphos. In the Paphos area, a low wooden structure predominates which is similar to the Ierapetra type from Crete (Fig. 16). About 67% of the greenhouses built are of this type. But wood is becoming more expensive and growers are increasingly turning to metal structures. In the long run it is cheaper to build metal greenhouses.

Two similar types are found in the Paralimni area, differentiated only by the presence or absence of gutters (Fig. 19). The trusses are driven about 75 cm into the soil but no foundations are provided; a stone under the truss prevents sinking.

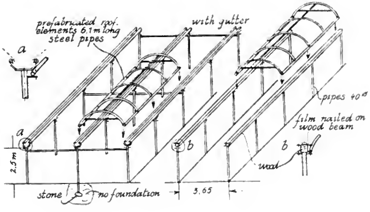

Fig. 19: Steel construction for Cyprus with prefabricated roof element.

When the houses are not fitted with gutters, the film is nailed onto a small wooden beam fixed at the top of the trusses. A rounded profile in which the film is held by means of a steel pipe completes the gutter of the other type.

The prefabricated round-arched roof structure, composed of steel pipes, is 6.1 m long. It is screwed to the gutter. This type affords several advantages, including low costs, easy assembly, high side-walls (which enable growers to use machinery inside the house) and the possibility of collecting rain-water.

Yet another steel pipe construction newly developed in Cyprus is shown in Fig. 20. This type suits both single-layer films and inflated double-layer ones.

Most of the recently built greenhouses are equipped with gutters designed to collect rainwater for irrigation. The water is stored in basins dug into the ground and made watertight by black plastic film.

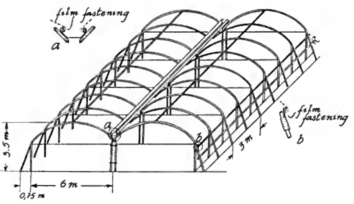

Fig. 20: Steel pipe construction from Cyprus

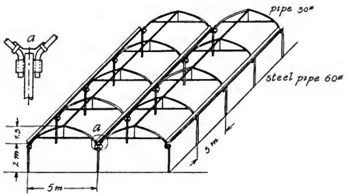

Fig. 21: Pointed arched type from Cyprus

In the Agricultural Research Institute of Nicosia, Cyprus, the pointed arched greenhouse type construction with gutters has been developed, and can be covered with both single and double-inflated plastic film (Fig. 21).

- **TURKEY** has about 6,000 ha of greenhouses, of which about 4,600 are covered with plastic film and 1,400 covered with glass. At the beginning of the development of plastic film greenhouses, wooden-frame structures were common. But wood became too expensive. As a result, steel pipe structures are now in use. These types are 3 to 4 m wide and about 2 m in height. They have side-wall ventilation; no roof ventilation is used. Recently, larger volume constructions have been introduced.

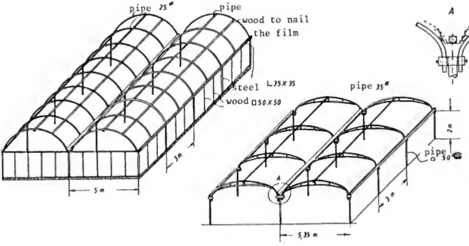

Fig. 22-23: **Two new types of highly performing greenhouses built in Southern Turkey.**

The two instances shown in Fig. 22-23 are worthy of interest. They have just been developed in the south of Turkey. The roof is a round arched one. They are highly efficient for a relatively low price.

The one on the left (Fig. 22) costs 2,000-2,500 TL (i.e.± 7-8 US $/m²). The one on the right (Fig. 23) is even more interesting; it compares favourably with the "Parral" model (equal efficiency for a lower price).

- **ISRAEL** devotes about 400 ha of land to greenhouse cultivation. A large majority of the houses are plastic-covered. Besides the simple wooden saddle roof structure they have developed several interesting constructions. Fig. 24 shows a shed-roof structure, over which the film is stretched by glass-fibre bars.

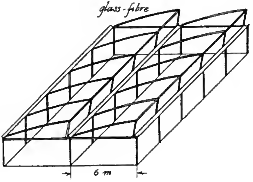

Fig. 24: Shed roof structure from Israel

The **saddle-roof type** (Fig. 25) is suitable for rigid plastics like polycarbonate or for single and inflated double film. The film is stretched at the ridge by a boosted apex.

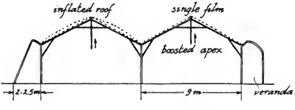

Fig. 25: Saddle roof construction (Israel).

Many Israeli greenhouses are complemented by a kind of corridor backed against the side-walls. The iron trusses and bars of the steel construction, with gutters and a sloped side-wall (Fig. 26), have a special design. Plastic ropes are fastened over the bars to stretch the film.

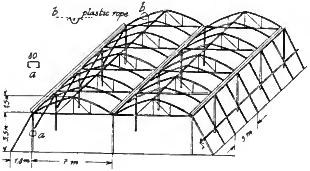

Fig. 26: Steel construction (Israel).

Another construction is the **tent type** (Fig. 27) with crossing steel pipe bars, which can be raised to stretch the film.

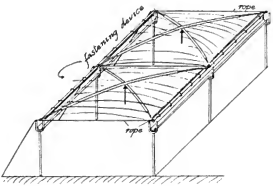

Fig. 27: Tent type construction from Israel.

Many greenhouses in Israel are fitted with trusses of relatively large diameter (3 inches and more). The reason is that pipes of a diameter over 3 inches are tax free !

In Table 11, some costs are given for greenhouses (structures + PE film single cover). The costs are in US $ per m² for about 1 000 m² floor area covered with single PE-film and with foundations included. It is very difficult to compare the prices !

Table 11 Costs of greenhouses with single plastic films in different countries (Prices in US-$ per m² floor area with single cover of PE-film and with foundations) (US-$ at 1/1/86)

Country	Greenhouse type	Approximate costs (US-$/m²) (structure + single PE cover)
Cyprus	Greenhouse as in Fig. 19	7.5
France	Round arched	6-9
Egypt		
Greece	Iron greenhouse	8
	Ierapetra-wood	5
	Wood + iron - Northern Greece	3
Israel	-	-
Italy	-	-
Lebanon	Round arched	5
Morocco	Delta 9	3
	Wooden structure	1.5
Portugal	Traditional type	2.5
	Improved type	3.5 - 3.75
Spain	Parral type	2
	Steel pipe 1" diam.	3.25
Tunisia	Round arched	7.5
Turkey	Glass	9.5-11
	PE wood frame	2.25
	PE steel frame	2.25-2.75

Considering the disadvantages mentioned above, the demands and the examples of plastic-film greenhouses from different countries, one can summarize the requirements for suitable types depending on the materials:

For all types construction

- Multispan greenhouses ventilated through side-walls and gables should not be more than 20 to 25 m wide to ensure efficient ventilation.

- For plastic-covered greenhouses, side-wall ventilation is the best and cheapest. Roof ventilation is too expensive.
- The height of the structure has to be limited in windswept regions. On the other hand, high and vertical side-walls offer the possibility of using machinery inside the house.
- In regions prone to snowfall, only singlespan greenhouses should be built.
- The greenhouses should be fitted for double film covering.
- Gutters should be used to collect rainwater. The cost of the gutter is repaid within a short time, and the gutter can be part and parcel of the construction itself. The film can easily be fastened to the gutter (see §3.1.4).

Wooden structures

- Saddle-roof types made of treated wood are suitable. Wood must be treated but phytotoxic products are to be avoided.
- Preparation consists of pressure-treating the wood with special chemicals (Copper sulfate, borax). The dry timber is left in the chemical solution for 2 to 3 days. The posts can also be charred at the surface.
- No nails should be used for fastening the film. The Portuguese method (also used in the South of France) of fixing wooden bars alternately one above and one below the film is both inexpensive and suitable. Another, but more costly, alternative is to use special fastening devices.

Mixed type from wood and steel pipes

- For plastic-covered greenhouses, curved roofs are more suitable because they make the film stretching easier.
- Curved roofs are also suitable for mixed types with trusses or posts made of wood and with a roof construction of steel pipes (types used in Crete and Greece, Figs. 17 and 18).

Steel construction

- Round or pointed-arched types suit steel constructions better than saddle-roofs, (e.g. the type described in Fig. 20).
- The effects of global radiation (eventually causing overheating) on the roof pipes in contact with the film have to be avoided. Therefore, the pipes should be painted white or covered with an insulating material.

In Fig. 28, a proposal for an inexpensive greenhouse construction is made. This particular construction has been built and, for the past two years, has been undergoing investigation as well as being in practical use. The greenhouse has the following characteristics:

- The construction is divided into two independent parts: the basic, supporting construction and the roof construction.
- Both wood and steel can be used for trusses and bars.

- A multi-span house should not exceed 20-25 m wide in order to ensure ventilation through side-walls and gables. Each individual span should be between 5 and 8 m wide so that the combination of 3 to 6 spans gives an overall width less than 30 m. In fact, the only factor limiting the width of the individual spans and their number is the efficiency of ventilation. A space of 1.5 to 2 m should be left between greenhouses.

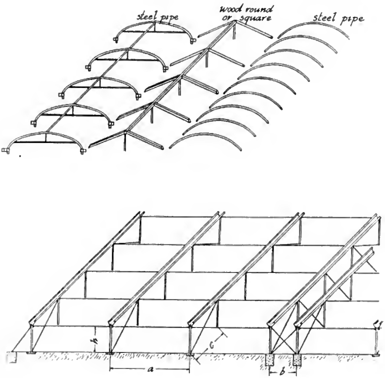

Fig. 28: Proposal for a new greenhouse construction with separate basic construction and roof construction for the combination of different types.

The key element of the construction is stabilised as a tent with tension rods, sloping tension wires connect the side-wall of one span at gutter level to the foundation of the trusses of the next house. In this way, the side-wall trusses are the only parts to sustain pressure and, as a result, to need deeper foundations. The inside ones rest on light foundations. The gutters are fastened to the tops of the trusses along the longitudinal axis, and the trusses are interconnected laterally by means of steel rods or wires. Gutters as well as rods or wires are stressed only by tension forces. As a consequence, the basic construction is simplified, relatively cheap and withstands the force of wind; constructional parts are reduced compared to those needed in other structures; light transmissivity is better.

- A ventilation structure is fixed to the side-walls, giving the space between two houses a double function: ventilating the house and stretching the construction.

- Gutters are used for collecting rainwater and also serve as "film-fastener". Collecting rainwater is necessary to reduce water shortage.

- The independent roof construction can be made of steel pipes or wood as shown in Fig. 28. One can choose the cheapest materials and the construction which meets the demands of the grower and builder. In general, one can say that a round or arched roof shape is better for stretching the film than a flat one.

- The roof construction has to be secured against wind forces separately.

- The best resistance against wind forces is provided by double-inflated films. The pressure between the two films is about 40 to 60 Pascal (4 to 6 mm water).

- Dimensions of the structure

  . Height (h) : 2 to 3 m

  . Distance between trusses (c) : 3 m

  . Width of span (a) : 5 to 8 m

  . Maximum width of a multispan unit : 20 to 25 m

  . Distance between two multispan units (b) : 1,5 to 2 m

- "Assembly Instructions"

  . Since trusses have only to sustain pressure, a light concrete foundation 10 to 20 cm thick will be sufficient.

  . The trusses, either steel pipes or wood, are bolted on to the concrete plate (Fig. 29).

  . Along the lateral axis the trusses are interconnected at the top by means of steel rods (12 mm in diameter).

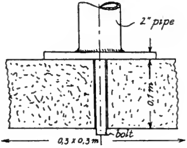

Fig. 29: Foundation for steel pipe truss.

- . The sloped steel rods at the side-walls (16 mm in diameter) are linked to the gutter and to the foundation. These foundations need to be 60 to 70 cm deep.
- . The gutters are attached to the top of the trusses along the longitudinal axis.
- . Between two multispan units the sloped rods are fastened to the foundations of the next greenhouse unit.

- Wood is as suitable as steel for the roof structure and, therefore, the choice will be guided by local prices.
  - . The roof structure is set on the basic construction and fastened to the trusses or gutters.
  - . The film is fastened to the gutters (e.g. by means of integrated fastening devices, as shown in Fig. 19 or 20).
  - . The greenhouse is ventilated through vents in the side-walls and gables, the construction of roof vents being too expensive for plastic-covered greenhouses.

This construction has some advantages and can help to improve plant production in the Mediterranean region. It is also adaptable to different national conditions.

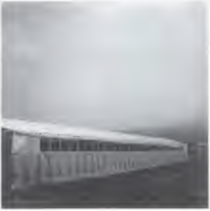

Fig. 30: Illustration of the Cretan Greenhouse, schematized in Fig. 16.

Ref: ZABELTITZ (von) Ch. (1985) : "New Construction of a Plastic-film Greenhouse" ACTA HORTICULTURAE 170, 25-28.

3.1.2 VENTILATION AS PART OF THE CONSTRUCTION

The ventilation of a greenhouse is the air exchange between the inside and outside atmosphere which performs the following functions:

- Exchange of oxygen and CO_2.
- Temperature control (removal of excess heat).
- Humidity control.

For optimal plant growth, adequate ventilation is very important in case of high outside temperatures, high global radiation and high humidity inside the shelter. This is especially true with multispan greenhouses.

One has to distinguish:

- **Natural ventilation** through openings in side-walls, roof or gable (= free or static ventilation).
- **Forced ventilation** by fans (= dynamic ventilation).

Measures for the ventilation of greenhouses are:

- the exchanged air in relation to the greenhouse volume:

Air exchange figure $Z = \dfrac{V}{V_G} \; \dfrac{(m^3)}{(m^3.h)}$ 3.1.2-(1)

(With this figure one cannot compare different greenhouses)

and

- the exchanged air in relation to the greenhouse floor area:

Ventilation rate $V_A = \dfrac{V}{A_G} \; \dfrac{(m^3)}{(m^2.h)}$ 3.1.2-(2)

With the average height of the greenhouse $\overline{H}$ one can calculate the relation of the two figures

$$\boxed{V_A = \overline{H} \;.\; Z} \qquad 3.1.2\text{-}(3)$$

By an energy balance one can calculate the ventilation rate, which is necessary to keep a certain temperature difference between the inside and outside temperatures. Fig.31 shows the relation between temperature difference and ventilation rate for a single covered greenhouse and a global radiation rate of 700 W/m^2.

The different curves mean :
a. for average transpiration;
b. without transpiration;
c. with high transpiration.

A ventilation rate of about 170 m^3/m^2 h is thus necessary to keep a temperature difference of 4°C.

For a floor-to-ridge height of 4 m and side-walls of 2.5 m, the average height of a greenhouse is 3.25 m.

The air exchange figure becomes (3.1.2-(1)):

$Z = 170/3{,}25 = 52{,}3$ (1/h).

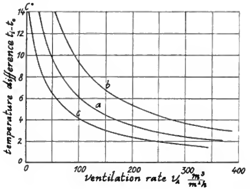

Fig. 31: Difference between inside and outside T° of greenhouse

The greenhouse volume has to be changed 52,3 times per hour by ventilation. The following figures are necessary for sufficient ventilation:

Air exchange figure Z more than 50 (1/h)
Ventilation rate V_A more than 150 (m³/m²h)

3.1.2.1 Natural (static) ventilation

Fig. 32 shows different ways of providing natural ventilation in a round-arched plastic greenhouse. In a non-arched construction, ventilation is easier, based on the same principles.

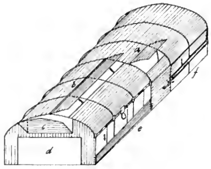

Fig. 32: Different ways of providing natural ventilation

Trap window roof ventilation (a) is simple but of limited efficiency. **Through-roof ventilation** (b) is better. This type affords a relatively good ventilation efficiency in multispan greenhouses too. But in the case of plastic-covered greenhouses, these roof ventilators add too much to the overall cost. So they are seldom built. Let us remember, however, the type of greenhouse designed by INRA Perpignan and the not so sophisticated but efficient Spanish "Parral" system (see § 3.1.1).

Side-wall ventilation and gable ventilation are the most frequent natural ways to ventilate plastic-covered greenhouses. Gable ventilation is obtained through trap windows (c) or doors (d). To provide ventilation through side-walls, it is best to open the whole surface. Let us point out however that 1.5 to 2 m of the side-walls at the edges with the gables should be covered with fixed plastic film in order to ensure air-tightness of the construction and rigidity of the structure. Ventilation can be provided either by lowering the film down to the soil surface by means of cables or ties (e) or by rolling it upwards to the gutter (f). However, in (f) the plants are more directly exposed to dry and/or cold air and the "border effect" is likely to increase. Straight side-walls are more suitable for side-wall ventilation.

To ensure natural ventilation a pressure difference must be created by wind or temperature gradients. The best way to generate such pressure difference is to make openings on both sides and along the ridge of the greenhouse.

- Free ventilation proves sufficient only in places and at times when the wind speed is high enough.
- In greenhouses, the drills (rows) must run parallel to the direction of the prevailing winds so as to increase the number of air changes per hour.
- In some regions, and above all at some periods of the year, horticulturists face serious parasite problems caused by aphids or whiteflies. Some growers protect the greenhouse openings with fine mesh nets. Such methods prove useful only when the reduced efficiency of ventilation (rise in temperature within the shelter) causes less inconvenience than the parasites and diseases do. This, some horticulturists claim, is the case in southern Spain, but a process like this is by no means to be generalized.

Ridge ventilation does not seem to apply to multispan plastic-covered greenhouses for reasons of cost; side-wall ventilation remains the most economical. The easiest way to open vents - either manually or automatically - is to roll up the film on a pipe. A number of automatic mechanisms have been developed and are now available on the market.

Ventilation openings in the side-walls of plastic-covered greenhouses often fail to be perfectly tight at the edges and, as a result, they flutter in the wind whether they are open or closed. A fixed film extending over a couple of metres along the edges with the gables reinforces the edges and improves tightness quite considerably. The movable ventilation can be made to overlap the fixed part. Fig. 33 shows a possibility that applies to inflated plastic-covered greenhouses. The side-walls are equipped with a rolling ventilation system: an iron tube makes it possible to increase the ventilation by rolling the two inflated layers of film upwards while pressing out the excess air through a self-opening valve. As only excess air is pushed out, the film remains inflated and stability against wind is improved.

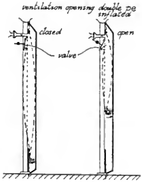

Fig. 33: "Side-rolled" ventilation of an inflated greenhouse with double PE film

Natural ventilation is obtained in single-span plastic film greenhouses simply by opening the film (a) or through ventilation windows (b) (Fig. 34). When the two films are held apart (a), considering the width of the greenhouse and of the sheets, ventilation rate will never reach 15-20% (20-25% are recommended in formula 3.1.2 (4).

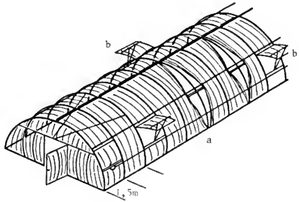

Fig. 34: Side ventilation in "round-arched" greenhouses.

Fig. 35 shows the French prototype. The rolling system fitted at the top of the house secures efficient ventilation but needs a lot of cables for operation. This could be perhaps adapted to side-walls and improved to facilitate operations.

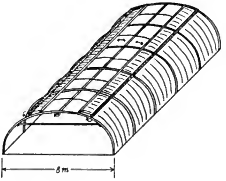

Fig. 35: Top ventilation by rolling tubes in an arched greenhouse

In the case of isolated single or multispan greenhouses provided with vent openings in the side-walls, ventilation is most efficient when the vents are at right angles to the prevailing direction of the wind, while in the case of grouped multispan greenhouses with spaces between the blocks they should be parallel to the wind.

For sufficient ventilation, the total vent area should be 15 to 25% of the floor area. If the ventilation is only through side-walls and gables the width of the greenhouse has to be limited.

$$\frac{\text{Vent area } A_V}{\text{Floor area } A_G} = 0.15 \text{ to } 0.25 \qquad 3.1.2\text{-}(4)$$

If the vent is about as long as the greenhouse ($W_G \times l_G = A_G$), the width W_G of the greenhouse can be estimated as:

$$\frac{W_V}{W_G} = 0.15 \text{ to } 0.25 \qquad 3.1.2\text{-}(5)$$

With a 15% vent opening and a 1.5 m wide side-wall vent on both sides, the width of the greenhouse becomes:

$$W_G = \frac{2 \cdot 1.5}{0.15} = 20 \text{ m}$$

With a 1 m side-wall opening on both sides, the width of the greenhouse becomes 13.3 m. Therefore, the overall width of multispan greenhouses should be limited to 20 to 25 m, and a space of about 2 m should be left between each block (see § 3.1.1) to provide sufficient ventilation.

For greenhouses covered with glass or rigid plastic, vent openings on both sides and the ridge are recommended. The total vent area should be 15 to 25% of the floor area. For single unit greenhouses the combined side-wall vent area should be the same as the combined roof vent area. Ridge vents should be top hinged and should run continuously the full length of the greenhouse. Top hinged vents should form a 60° angle with the roof when wide open.

3.1.2.2 Forced ventilation

Forced ventilation by fans is the most effective way to ventilate a greenhouse but it is electricity consuming. The principle of forced ventilation is to create a flow of air within the structure : fans fitted on one side suck air out and openings provided on the other side let air in.

Some key elements are worth mentioning:

- the fans must exhaust air out of the greenhouse. Exhaust fans improve the temperature distribution within the structure and avoid any damaging over-pressure inside;
- the distance between any 2 successive fans - placed on the same side (end) of the greenhouse - must not exceed 8 to 10 m;
- ventilation fans should deliver the required ventilation capacity at approx. 30 Pascal static pressure (3 mm water);
- whenever possible, the fans will be located on the side of the greenhouse opposed to the direction of the predominating wind;
- a clearance between the fan discharge and any obstruction of at least 1.5 times the fan diameter must be maintained;
- the intake opening on the opposite side of the fans should be at least 1.25 times the area of the fans;
- the velocity of the incoming air should not be too high;
- the openings must close automatically and be totally airproof if the ventilation fans are not in operation.

Fig. 36 shows the principle of forced ventilation with a very simple self-closing opening for the incoming air.

Another type of self-closing opening system is schematized in the same Figure 36. It has the advantage of preventing excessive air flow directly onto the plants (upper left corner).

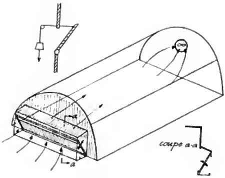

Fig. 36: Forced ventilation on gable of the house
(Case of arched single-roof construction)

The electric power of the fans can be calculated by multiplying the air capacity necessary for ventilation by the pressure loss through the greenhouse divided by the fan efficiency.

If one uses the ventilation rate for any square metre of greenhouse floor area one obtains the electric power per square metre.

i.e.

$$P = \frac{V_A \cdot p}{\eta} \ [W/m^2] \qquad 3.1.2.-(6)$$

where:

V_A ($m^3/m^2 . h$) = ventilation rate (c.f. fig. 31)

p ($P_a = N/m^2$) = pressure loss

η (-) = fan efficiency

With a pressure loss of 30 Pascal (3 mm water), a ventilation capacity of 170 m^3/m^2h = 0.047 m^3/m^2s (Fig.31) and a fan efficiency of 70% one can calculate an electrical power of:

$$P = \frac{0.047 \ . \ 30}{0.70} = 2.014 \ W \ m^2$$

The electrical power is about 2 W per m² of greenhouse floor area during the operation time. In other words, for a system that works 9 hours per day, ventilation consumes about 18 Wh/m²/day.

Thus, a 1 000-m² greenhouse "consumes" about 18 KW of electricity per day, provided the fans work a 9 hour period every day.

The air volume for ventilating the greenhouse by fans is

$$V_f = V_A \cdot A_G \quad (m^3/h) \qquad \text{---} \qquad 3.1.2\text{-}(2)$$

With a ventilation rate $V_A = 170$ m^3/m^2h and a greenhouse area (A_G) of 1,000 m^2 the required volume of air is

$$V_f = 170\ 000\ m^3/h$$

If one fan develops, for example, a capacity of 25,000 m^3/h, 7 fans are needed to ventilate the greenhouse.

ZABELTITZ (von) Ch., (1978) : "Gewächshaüser, Planung und Baü" - Ulmer Verlag, Stuttgart, 1° Auflage.

Idem (1986) : 2° Auflage.

3.1.3 COVERING MATERIALS

3.1.3.1 Description of the materials

Present-day greenhouses in Mediterranean countries are, on the whole, covered with Polyethylene films. Films from other resins (Polyvinyl chloride, Polyesters, etc.), are rare exceptions. Rigid materials, such as glass or twin-wall plastics (two rigid sheets joined at regular intervals by "bridges" acting as cross-members) are very interesting in northern areas but they appear too expensive if their life-span does not exceed 7 to 10 years and require too sophisticated or too strong structures to be profitable in Mediterranean countries.

A. Polyethylene films

As stated above, the basic material for most of the plastic films used in the Mediterranean area as greenhouse and shelter covering materials is polyethylene. Addition of enrichments to the basic PE resin increases, to a certain extent, the film's durability, modifies its transparency to the visible and short infrared (solar radiation) and can influence its qualities of absorption and reflection for the long infrared. It is, therefore, very interesting for the user (horticulturist) to know the nature of the additives used during the extrusion of the films proposed by different manufacturers.

A.1. Low density Polyethylene (LD-PE)

In fact, there exist two different qualities of LD-PE : the radicular and the linear types. Radicular Polyethylene is obtained by polymerization under high pressure and at high T°, while for linear PE, the pressure and T° are much lower. Linear PE films have a better mechanical resistance but are very extensible (reversible elongation) and, therefore, difficult to produce in great width. Hence the difficulty of using the film as greenhouse cover in its pure state. However, a mixture containing 20 to 30% linear PE is useable. For small tunnels, thin linear PE films (80 to 120 microns) produce better results - due to their improved mechanical resistance - than radicular PE measuring 120 to 150 microns.

Not only is the film's useful life dependent on stabilizing substances (UV absorbers) but also on resin quality, characterized by the "fluid index" or melt index (M.I.). Low fluid indexes (0.3-0.7), which are the result of a high degree of polymerization obtained under high T° and high pressure, allow the extrusion of so-called "two-star films" with good mechanical properties. The lifetime of such films can be very long provided sufficient good quality stabilizers (UV absorbers mainly) are used. Under north Mediterranean conditions, 4-year lifetimes are a reasonable expectation, while further south, they do not exceed 3 years. In fact, in most cases, lifetime is shorter because the fluid index of the resin and/or the stabilizer quality or quantity presents some deficiencies. The use of different stabilizers in PE to obtain Long-Life - PE reduces transparency to solar radiation but increases absorption of long IR, so LL-PE provides higher night T° and better agronomic results. With a view to obtaining highly transparent LL-PE films, a new generation of stabilizers (HALS) has been experimented on but these react with some fungicides containing sulphur, used in the greenhouse.

A.2. Vinyl Acetate Polyethylenes (E.V.A.)

The polyethylene making up the basic resin is enriched with Vinyl Acetate (VA) whose property is to increase the absorption of the long IR in the film without reducing its transparency to UV, to the visible and to the short (solar) IR. On the contrary, though EVA's are known for their high initial transparency to solar radiation, this quality can disappear more or less rapidly due to higher dust retention, especially in climates with low rainfall.

The higher the VA content of a film, the greater the quantity of long IR absorbed (i.e. the greenhouse effect developed by films). However, total absorption of long IR cannot possibly be achieved since there exists an upper limit to the VA content which, if exceeded, would incur degradation of the mechanical properties of the film due to the progressive lowering of the softening point (manual traction at testing, differential tractions when the film is laid on the greenhouse) and when overheating occurs on the ring bows of the greenhouse frame. Nowadays, the VA content of the EVA is seldom in excess of 14%. An 18% VA content seems at present to be the extreme limit from the point of view of creeping, yet it still does not offer total long IR absorption.

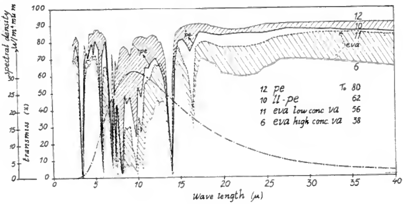

Fig. 37: Long IR transmittance of 2 PE : "normal" (12) and "Long-Life" (10) and of 2 EVA : "poor" (11) and "rich" in VA (6). Spectral density of the black body (300°K) (*)

(*) Cf. NISEN A, et al. (1984) : "Détermination des propriétés radiométriques des matériaux plastiques utilisés en couverture de serre - ACTA HORTICULTURAE, 154, 19-32 Hammamet.

VA shows specific absorption in the long IR; these absorption rays are thus different from those of the other substances added to the basic resin (see § A.3.) and they influence differently the thermal balance of a greenhouse. Consequently, VA and other thermal charges are not interchangeable when used to help reduce the transmission of the long IR.

UV absorbers are likely to increase EVA life (= Long-Life EVA) but durability may decrease with a higher degree of VA content of the resin : when EVA is too rich in VA, it seems to be less resistant to anti-UV load.

A.3. Infrared Polyethylenes (= IR-PE) (or "modified" PE).

In this case, the basic PE resin is enriched with aluminium silicate or with magnesium silicate. The "thermal" effect on the film is obvious, but extensive use of such "thermal charges" may cause inconveniences; e.g. impurities of aluminium silicate will accelerate ageing of the film. Just for the VA addition, no material can be obtained that can combine high opacity to long IR, excellent transmission in the solar along with good mechanical properties. Plastic producers are to limit the levels of concentration of IR charges so as not to reduce film lifetime and transparency; generally, the charge content cannot exceed 5% (maximum 8%).

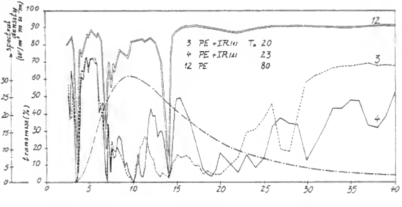

Fig. 38: Long IR monochromatic transmittance of a "normal PE" (12) and of 2 different IR-PE (3 & 4)

A comparison of Figs. 37 and 38 shows that the VA and the thermal charges absorb respectively and preferentially certain parts of the long IR spectrum.

A.4. Thermal Polyethylenes (or EVA with additives)

Neither VA nor IR charges taken separately are likely to offer a satisfactory solution to the problem of creation of Long-Life PE films totally absorbing the long IR. This has led to the creation of a new generation of PE films which, according to their inventors, should have the combined advantages of the EVA's and of the IR-PE's and avoid their inconveniences. Indeed, some so-called "thermal" films absorb more long IR than the IR-PE's and the EVA's do; they derive from LL-PE resins simultaneously enriched with a presumably optimum dose of VA and of thermal charges. The practical results achieved recently by some such films look promising, and this way seems to be the best to follow at present.

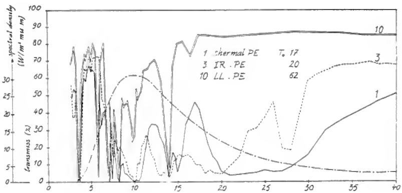

Fig. 39: Long IR monochromatic transmittance of LL-PE (10), and IR-PE (3) and a thermal PE (1)

It is interesting to note that two different "thermal PE's" can show very different absorption curves and, consequently, very different practical "horticultural" value in relation to the nature of thermal charges and the quantity of VA and charges they contain.

Remarks

"Charged" PE's often present lower mechanical properties than "normal" LD-PE. Their use as greenhouse cover can present some difficulties or their lifetime - when stretched over the greenhouse - risks being reduced.

- Therefore, when two sheets (one "normal PE" and one "charged PE") are to be combined into a double insulating wall, it is best to assemble them with the thermal PE inwards when installed on a greenhouse: in this way, the more brittle material is protected.
- Nowadays, multi-layer films raise great hopes; they are obtained by co-extrusion and combine all the qualities required, i.e.:

- . the mechanical strength, resistance to flowage creep, durability, anti-adherence and anti-dust of ordinary PE
- . the thermal effect and light transmission of EVA.

Conclusions

The horticulturist cannot be denied a maximum of information about the chemical composition of the basic components of the film he buys:

- the cultural results are definitely linked to the type of film actually used: "ordinary" PE (long-life or not), EVA, IR-PE or thermal PE (unless the climate conditions cause large quantities of water drops to adhere permanently or nearly permanently);

- on the other hand, materials with equal average IR transmittance may lead to rather different thermal balances under shelters ("k" coefficient). The photometric data obtained by classical methods have to be interpreted to underline such differences.

B. Non-polyethylene films

A number of other films are or are about to be used commercially; the oldest of them being of course polyvinyl chloride (PVC), but there exist many more: vinyl polyfluoride (PVF or PF), terephtalate polyethylene as well as many other polyesters. New materials keep on invading the market (such as polyurethane, polystyrene...), characterized either by quite an original basic chemical nature, by a better mechanical resistance, by a higher transparency to solar radiation, by an increased lifetime or by a lower transmission within the long IR.

These materials remain rare or still do not exist in the Mediterranean zone but may gain more importance in the near future.

The respective transmittance properties of all those materials for the visible and the solar IR do not actually differ fundamentally from each other. Furthermore, their chemical composition is seldom disclosed, which leaves the user with little choice but to trust the producer and accept the long IR transmittance values proposed.

A Mediterranean "quality label" would prove highly interesting to the horticulturist and would avoid many a difficulty.

Since these materials differ little on the point of solar radiation transmission their suitability for covering greenhouses will be determined mainly by their ageing pattern, by their absorption (or reflection) of the long IR and by their mechanical traits. Let us point out, however, that a number of materials that could prove excellent in horticulture are useless because they are only available as narrow films.

Two materials, fairly different from classic PE's and which have long been known, are now being thoroughly surveyed by the firms which market them: "polyvinyl fluoride", better known as 'Tedlar', and a polyester (or terephtalate polyethylene) being traded under the name of 'Terphane'. They are likely to regain market soon - due, among other reasons, to their excellent photometric characteristics - provided their prices remain competitive...! However, this study will be limited to polyvinyl chloride (PVC) which is better known to extension staff even if not widely used in the Mediterranean Basin.

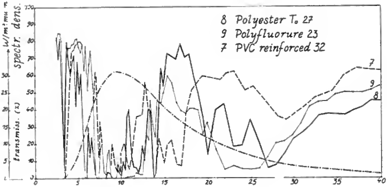

Fig. 40: Long IR monochromatic transmittance of a Polyvinyl Fluoride (9), a Polyester (polyethylene terephtalate) (8) and a Polyvinyl Chloride (7).

B.1. Polyvinyl chloride (PVC)

Contrary to PE, PVC is not flexible by nature (it is used e.g. to manufacture rigid pipes). Plasticisers may be added to create plasticized Polyvinyl Chloride (P-PVC) that can be produced as a film either by rolling (pressing) - width limited to 2 m - or by extrusion - swelling - up to 6.5 m wide. The migration of plasticisers may cause ageing to occur more or less rapidly. In the Mediterranean region, P-PVC films (50-80 μ) are used mainly to cover low tunnels, yet in Japan specially designed structures allow this material to be used to cover greenhouses. Reinforced P-PVC films are sometimes used to cover complex walls such as the higher parts of the gables, since they weld easily.

Addendum : "Textiles" (*)

Over recent years, "textiles" have taken on a spectacular extension in agriculture, though the phenomenon is not yet generally recognized.

The "geotextiles" in various forms, i.e. woven, knitted, non-woven and heat-sealed in Polyethylene (PE) or in Polypropylene (PP), have been used in agriculture in drainage, packaging, thermal screens and shadings for greenhouses as well as unsupported covering materials for crops. These types of geotextiles are now called "agro-textiles"; those for horticultural purposes are mainly non-woven, manufactured according to the principle of direct spinning and thermo-welding. Some polyamides (PA) and polyesters also enter into the fabrication of these agrotextiles.

(*) BAUDONNEL, J. & SOTTON. (1985): "Propriétés des textiles à usage agricole et horticole". Plasticulture, 66, 45-56, PARIS

The agrotextiles are very light, thin and flexible; generally they are homogeneous and present a high porosity which is not localized as is the case for perforated films but rather distributed on the scale of fibre interlinks; this combination of properties enables non-wovens to be used for semi-forcing since they offer all the characteristics (mechanical strength, permeability to fluids and radiation) required for a thermal screen creating a greenhouse effect.

Measurements have been carried out between 2 and 50 μ for the IR and 0.2 - 0.7 μ for the visible and UV. In the main, the agrotextile coverings transmit solar radiation at a high level (especially the PP and some PA ones) (80-90%) and effectively block the IR to give a good greenhouse effect (20-30% transmission).

According to the authors (*), an amazing future lies ahead for agrotextiles...!

C. Rigid covering materials

Up to now, rigid materials have been little used as greenhouse cladding in the Mediterranean basin. However, they give rise to slow but steady interest in the northernmost regions.

These materials are suitable for the construction of twin walls as well as of single ones. Twin walls undoubtedly cause a certain reduction of light transmission. However, absorption in the long IR is generally good (polycarbonates) or even complete (glass, polyester, PMMA (polymethylmetacrylate)...).

C.1. Glass

Everybody is familiar with window-glass ("drawn" or nowadays "floated") and 'hammered-glass' (cathedrale, diffusing...). These two products are derived from the same basic material but differ in presentation. The first of these is here called "horticultural glass" (VH).

Though their behaviour as greenhouse cladding has been carefully examined for the last few years, opinions are divided over the diffusing properties of the 'hammered-glass' which are even virtually non-existant. However, both types, which absorb the long IR completely and have a good transparency to solar radiation, definitely possess the well known "glasshouse effect".

Other types of glass are being marketed. Coated glass or low emissivity glass (VH^+ in the following figures) seems to perform well in a Mediterranean climate with clear skies and moderate winds. Provided that minor additional expenses are accepted, coated glass will prove nearly as insulating as tight double glazing, the latter being much more expensive and heavier per unit of surface. The coating, giving to VH^+ its low emissivity properties, can be orientated to the outside of the greenhouse (VH^+_{11}) or to the inside (VH^+_{12}); the behaviour of VH^+ (=conductivity), is not the same in the two cases (see Fig. 43).

In the coldest areas of the Mediterranean basin, glass, above all when coated, ranks second to none as a covering for greenhouses intended for ornamental plants. Statistics show, however, that its use is an exception at these latitudes.

(*) BAUDONNEL, J. & SOTTON. (1985): "Properties of textiles for agricultural and horticultural use". Plasticulture, 66, 45-56, PARIS

C.2. Reinforced polyester

These polyesters, generally glass-fibre reinforced, form a group of rather polymorphous materials difficult to characterize for the user. They are the result of the action of acids on polyvalent alcohols. But the acids and alcohols which may generate a 'valid' product make up a long list which, combined with the large variety of reinforcement fibres, end up in products with a wide range of 'horticultural' properties.

Greenhouses definitely require special "greenhouse" polyesters securing at least 80% of global light transmission (against the 60 to 65% commonly found in materials destined for buildings). They must be relied upon not to lose more than 20% of their global transmission when used over a period of 10 years (the growers must ask for a "10-year guarantee"). This involves the use of top level resin and prime quality surface protection: acrylic gel-coat or polyvinyl fluoride coating or ethylene terephtalate coating.

Their future in the Mediterranean area might look brighter if their prices remained competitive and, above all, if lighter structures than those used for glass could suffice and if their stability with age could improve. These materials are more successful in Spain than elsewhere.

Flat sheets are preferred to corrugated ones (which have a larger exchange surface) to improve the thermal balance of polyester-covered greenhouses. However, this choice implies the building of more rigid frames: indeed, a flat material requires stronger and more regularly distributed support.

N.B. PMMA single wall plastic boards are currently used in Crete and Italy.

C.3. Double walls

Double walls now exist in a large variety of materials. Some are air (and water) tight (where glass is being used) and others are not (where synthetic materials are being used). They do have insulating power but it decreases noticeably with the loss of air tightness.

On the other hand, the double walls increase the low night temperatures, which is very favourable in arid climates, but they also increase - and often in a larger proportion - the day thermal maximum temperatures, which can prove damaging in the same climate.

C.3.1. Twin-wall glass materials

Although frequently used in northern or continental climates, those materials which are perfectly tight - and consequently quite expensive - do not prove very useful in the Mediterranean region.

C.3.2. Twin-wall plastic materials

As noted above, these twin-wall materials are made of open spaces formed by two rigid sheets of plastic joined at regular intervals by "bridges" acting as cross-members which demarcate, with their external walls, channels of various sections. These products are very different from the twin-wall glass materials, especially because of the presence of these cross-bridges which are responsible for their rigidity. This twin-wall plastic sheet has been promoted in horticulture under the German name of Stegdoppelplatte (SDP) by a manufacturer with a material produced from polymethyl-methacrylate (PMMA). Other resins can be used that will produce similar looking materials although presenting different photometric and thermal properties, e.g. Polycarbonates (PC) and even Polypropylene (PP).

In spite of the positive results of experiments carried out namely with PMMA. in Kuwait, among others, these materials are not in a position to compete, in the short term, with those described below, in the Mediterranean region.

C.3.3. Twin-walls made up of plastic films

The desire to grow vegetables and plants all the year round in the Mediterranean zone has resulted in the use of plastic twin-walled greenhouse coverings (mainly polyethylene).

Horticulturists themselves have improvised a twin-wall: they devised a system to fix a second film at a short distance from the first. They have also invented a system to fix a transparent film in a horizontal plane about one metre from the top of the tunnel. The film unrolls along the side-walls and acts as a thermal screen when placed in position (unpacked) at night and packed during the day.

Greenhouse manufacturers have also developed a twin-wall system in which the two films are kept distant from each other either by the tension exercised on them or by inflation with air (= inflated double skin). This system, which is very interesting in many respects is, unfortunately, limited to a number of Mediterranean areas because of its high cost and of the need for electricity within the greenhouse.

It is not necessary to write more in this chapter about these "plastic twin-walls". Their thermal properties, in relation to their conception and realization, will be given further on.

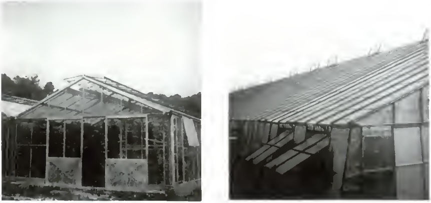

Fig. 41: Two different types of glasshouses in ANTALYA (Turkey)

3.1.3.2 Properties of the covering materials

It is not useful to specify, in a work such as this, every individual physical or mechanical characteristic of all the materials which are being marketed now and are likely to be used in a greenhouse cover. Only the main aspects of the photometric and thermal characterization of the materials most commonly used in the Mediterranean basin will be discussed.

The properties of the main materials used as greenhouse cover in the Mediterranean zone are featured qualitatively in §3.1.3.1.

Since the most frequently used materials are – in the field of solar radiation – completely transparent or slightly coloured, their radiometric properties hardly vary with the wavelength. Consequently the values for the visible, the near IR, the total solar and the PAR (photosynthetically active radiation) differ only by a few percent.

As far as the long IR is concerned, absorbing materials are preferred and the spectra of the films currently used differ appreciably one from another (Fig. 38 to 41). These monochromatic data – which incidentally are easy to set up – provide only a qualitative understanding of the problem. However, efforts must be made to derive quantitative values from them because of the real agronomic meaning these values represent.

The methods differ amongst authors. Consequently, there exist large differences in the quantitative results proposed in the literature, especially as most publications fail to state the exact chemical nature of the materials (cf. § 3.1.3.1). Tables of values would have to propose wide ranges for each material and are therefore totally useless. However, "k", the coefficient of thermal conductivity of materials, will be given; the values listed were obtained by the method described below; see footnote(*). The respective values of the "k" of each material are derived from its photometric properties under perfectly defined weather conditions (temperature inside and outside the greenhouse, nebulosity, wind speed, etc.).

N.B. It seems thus perfectly useless to present here more or less complete tables showing precise values of transmission and reflection in the visible, the total solar and the long infrared for a number of covering materials. Indeed, the values are bound to vary not only with the manufacturing conditions of the materials, their thickness, their cleanness their age,... but also with the quantitative and qualitative chemical nature of the materials themselves and of their additives (cf.§ 3.1.3.1 A.) It would therefore be absolutely impossible for the reader to find on the market one of the materials described in such tables. The only aims of the document below are:

- to direct the reader's attention to the large number of diversified materials on the market;
- to urge him to obtain from the supplier precise information concerning the chemical nature of the material, including the content of its additives;

(*) J. NIJSKENS et al. (1984). "Propriétés radiométriques et thermiques des matériaux plastiques" - ACTA HORTICULTURAE, 154, 33-39. - Hammamet.

- to advise him to obtain from his supplier the name of the laboratory that determined the photometric and thermal properties of the materials offered as well as the complete results of the determinations carried out;
- to resort to the authors of this book if he cannot make up his mind or in case of litigation;
- to compare, under the prevailing local conditions, the technological and economical characteristics of the material considered.

A. Average factor of transmissivity of covering materials

Fig. 42 gives some general values of the transmittance factor for solar radiation and for the far infrared of some types of materials.

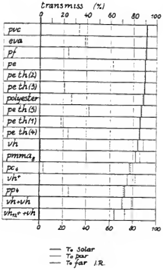

Fig. 42: Average factor of transmittance for total solar radiation, for "P.A.R." and for far IR of some materials

It appears immediately that:

- all single wall materials fit for greenhouse covering have practically equal transparence to total solar radiation, all the values being contained in a 5% bracket (92 to 87%);
- only special materials VH^{+} = low emissivity glass and double wall glasses - (bracket 78 to 72%) - bring about a noticeable reduction of factor of transmission to total solar radiation. Double wall PMMA looks particularly transparent. In the case of glass double glazing, a low emissivity layer also accounts for a reduction in transmission (from 72 down to 66%);

- some PE's are slightly coloured. Even if the influence of such coloration on the spectrum of transmission is detectable, it can be neglected under Mediterranean conditions : reduction by 2 to 3% of some wavelengths of the visible !

- as to the transmission factors of the materials in the far IR, it must be observed that the films - above all non-charged PE's - are generally transparent, and that the polypropylene double walls (4-mm thick : PP4) are not basically different from the films previously mentioned; the other materials absorb nearly all the far IR;

- the transmission factor for the light diffused by the sky is somewhat lower than that for total solar radiation; however, the materials are always less transparent under a cloudy sky than under a clear one. These observations are well worth considering : the solar energy received under a cloudy sky is less than that measured under a clear sky and, furthermore, the materials react less favourably : the "loss" of light is consequently "double".

B. Thermal conductivity : coefficient "k"

Let us keep in mind that "k", which, at first sight, looks relatively simple to express, is neither determined nor used easily. A number of parameters are taken into account to assess it : temperature of intersideral spaces, temperature inside and outside the greenhouse, wind velocity, etc. Such parameters frequently render the values proposed by different authors impossible to compare. Furthermore, since some covering materials are only partially opaque to long IR's, "k" cannot be determined mathematically unless every single term of the thermal balance is assessed correctly. And this is no easy task. Finally, it must be remembered that the "k" of a given material, assessed mathematically or determined in laboratory where precise and static conditions prevail, cannot closely match the "k" of a greenhouse where the size, orientation, tightness, etc. add to the changing and dynamic conditions of the building.

B.1. Standardized values of "k"

Provided some parameters are determined : vertical wall, wind velocity (4 m/sec), radiative outside temperature (linked to outside temperature) - 28°C, outside temperature of air : 0°C, inside temperature : 20°C, it is possible to establish a Mediterranean value of "k" for some covering materials (See Fig. 43).

The figure shows that :

- heat losses under PE are well above those under glass (in the theoretical conditions used in Fig. 43 : 9 against 6.1 $W.m^{-2} K^{-1}$); But in practice, it must be taken into account that a greenhouse (covered with PE sheet) is generally more air-tight than a glasshouse (covered with glass); the "k" value of the PE covered building is "better" (i.e. lower) than shown as a result of theoretical calculation in which the constructions are evenly tight;

- even when presented as a double wall (from 20 to 50 mm of dry air), PE insulating power is inferior to that of glass (6.4 against 6.1 $W.m^{-2} K^{-1}$);

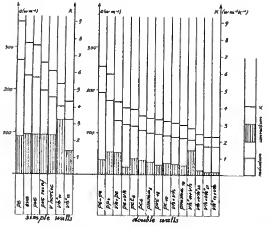

Fig. 43: Radiative energy and convective energy through different materials in the above conditions. "k" values obtained from these data (scale on the right). (Horizontal lines on the graph)

These differences are explained by the relationship between heat transfer by conduction-convection and heat transfer by radiation : the quantity of energy transmitted directly by radiation is practically the same whether the PE sheet is double or single (159 against 180 W.m^{-2}). However, the energy transmitted by conduction-convection is reduced by three, due to the air cushion between the two sheets of a double wall (34 against 90 W.m^{-2}). It is obvious from this schema that double wall PE can be very interesting in the regions where energy losses are of the conduction-convection type (north) but less effective against radiative energy losses (south);

- **modified PEs and PVC films** compare favourably with glass at the level of conduction-convection transmitted energy. Moreover, their "k" comes closer to the "k" for glass as their transparency to long IR's grows weaker : it can be up to 20% lower than that for ordinary PE, which is by no means negligible;
- the "k" of double walls composed of an "ordinary" PE film and an improved PE one comes closer to the "k" of PE double-wall composed of glass and PE as the transmission for the long IR of the reinforced PE is weak.

N.B. It must be kept in mind that these values can only serve as an indication. Indeed, the "k" that can best help establish the thermal balance is that of the greenhouse over a given period of time accompanied by the normal changes in climate conditions. However, even under other climates, the "classification" of materials proposed here remains unaltered. The only parameters to vary are the absolute values of "k" (see below).

B.2. Variation of "k" with external conditions

When a change appears in the conditions prevailing at the time "k" was calculated, the following may be observed:

a) The **wind effect** is similar on any material regardless of the presentation (single or double wall): "k" rises noticeably when the wind speed passes from 0 to 4m/sec, but does not undergo major changes for further speed increases. **Double walls** are obviously less sensitive than single ones (Fig. 44).

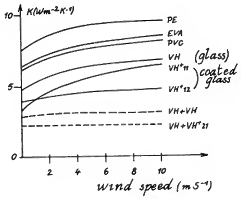

Fig. 44: Influence of wind speed on the "k" of some materials

b) The radiative temperatures of the sky and of the air are much the same under **overcast sky**. This reduces heat losses through the material around intersideral spaces and consequently "k" decreases (as compared to "k" under a clear sky). In other words, transparency to heat is greatest (maximum "k") when the sky is clear (and the external temperature may reach its low point). Conversely, "k" reaches its minimum value and heat losses through materials are reduced when the sky is overcast and when external temperatures are unlikely to be low.

c) Similarly, it is in cold **climates** that a PE cover looks the least favourable and in temperate climates (overcast sky) that the "k" of ordinary PE is the closest to the one of glass.

d) **A thin film of water** on the internal side of a material (PE) greatly reduces its "k": it absorbs the far IR totally, which virtually reduces the "k" of "wet" PE to that of glass. The "advantages" recorded by IR or thermal PE films are decreased "ipso facto", compared to normal PE. There remains, however, a problem to settle: must the cover of a greenhouse be of "anti-drop" PE, i.e. one which transforms water condensation drops scattered on the surface into a continuous film absorbing the far IR or is it better to use "modified" PE's? In the Mediterranean region and in the (semi-) arid zones, the "charged" films look more interesting (thermal PE or IR-PE) since they act over a longer period of time and in conditions where the "k" of an "anti-drop" PE would be high. Each case requires an individual approach.

e) No relation is observed between the thickness of a covering material and its "k"; it is, therefore, useless to utilize thicker films with the aim of reducing heat losses through them. The thickness of a material must be determined by the mechanical strength required and by the expected durability of the cover.

N.B. It should be remembered that, since every climatic factor has a specific influence on the "k" of any material, the value calculated for a greenhouse over a given period of time records fewer variations : it proves of greater stability. Nevertheless, the classification remains unchanged.

B.3. "k" for plastic double wall greenhouses

When two plastic films are correctly associated, i.e. when the distance separating them (whatever the external conditions) is between 5 and 10-15 cm and when the volume is airtight, the relation between the "k" studied above for a vertical wall and the "k" of a greenhouse is satisfactory. "k" is always lowest in the most sophisticated systems (e.g. inflated greenhouses).

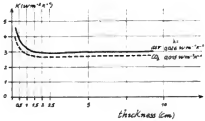

Fig. 45: Influence of the thickness and of the nature of the gas kept within the two walls of a double glazing on "k"

However "home-made" systems designed by horticulturists may prove economical when the "manufacturing" cost is not offset by an exaggerated increase in "k". The reduction of light (§ 4.1.2 - "Light") due to the constant presence of the second PE film must not be overlooked, even in the Mediterranean climate. (This is even truer when the film gets dirty or has not been correctly laid). Indeed, such a reduction causes delays in winter growth unless it is offset by an appreciable increase in thermal conditions. An incorrectly built double wall may prove harmful rather than beneficial since it has little impact on the "heat losses" aspect in the thermal balance of the greenhouse but causes serious light loss and reduces the available solar energy. (= "asset" in the thermal balance of the shelter).

From another point of view, it goes without saying that the best PE to line a normal one is a "modified" one (IR or thermal) : indeed, the reduction of "k" resulting from the presence of a layer of air is complemented by a further reduction generated by the insulating properties of the "charged" material and the light loss can be reduced.

There remains yet another question to answer: is the "modified" PE to face the inside or the outside of the greenhouse? The thermodynamic answer is complex and depends on the percentage of heat transmitted by radiation or conduction. However, it is the material with the least mechanical resistance which has to face the inside of the greenhouse.

B.4 Thermal behaviour of glass and coated glass

As previously mentioned, the theoretical insulating power of glass - considering the climatic conditions of clear winter nights in the Mediterranean region - competes, even favourably, with that of films when presented as a single wall (whatever their chemical structure) and with that of ordinary PE presented as a double wall (when the air-tightness of the different constructions compared is the same).

It has also been shown (Fig. 42-44) that the "k" of a low emissivity glass is lower than that of ordinary glass. In dry weather (and when radiation is strong at night) low emissivity glass is most likely to exhibit insulating properties which are about 30% higher than those of ordinary glass. On the other hand, in humid weather and when there is water on the low emissivity side, this coated glass tends to behave just like ordinary glass.

This material does not need any further consideration since it is not being used in the Mediterranean region at present.

C. Degradability of plastics

To the horticulturist, the "ideal" durability of the synthetic materials that he uses is that which corresponds to the number of cultural cycles that he has undertaken to carry out in each particular case : 4, 6, and even more under a given greenhouse cover in Europe (= 3 years and over) or a single cropping season (mulching of main plants). The number of cycles is often governed by economic reasons.

The general tendency is to lengthen the "natural" durability of plastics, and this is especially true when they are used as greenhouse cover. In some cases, however, the reverse may be sought, e.g. when a film should leave the slightest possible quantity of remainder on the field so as not to hamper subsequent cultural practices, e.g. ploughing after maize mulching.

Theoretically speaking, two different processes can accelerate the degradation of plastics: a chemical or biological process (biodegradability) and a physical one (photodegradability).

It is the first type of degradation (biological) which is the most often spoken of, even though it is in this field that the techniques are the least used: indeed, biodegradable plastics are not mass-produced and do not actually exist outside laboratories or pilot-workshops. The formulation is to be enriched with "nutritive" fillers that the soil microorganisms will attack in the first place, causing the disappearance of a reasonable portion of the film within a given time.

Most plastics, and obviously the so-called commodity ones (PE, PVC, PP...) are photodegradable by nature under the combined effect of UV radiation-oxidation heat, mechanical fatigue... The photodegradable films (mainly PE) in fact degrade along a programmed path linked to the addition of special elements which cause an irreversible process of ageing (destruction). They are strictly kept as mulching material for some tall crops such as maize, tomato, cotton. They are 5% or so more expensive than ordinary PE films.

Conclusions

The chapter devoted to covering materials is complex and not easy to read by nature: the authors have tried to assemble a large collection of data likely to inform the reader and to serve as a guide in his prospective choice.

Indeed, this choice is of paramount importance and may have a long-term influence on the greenhouse production of a whole country. It must be made on good grounds, irrespective of publicity data which sometimes lack precision if not accuracy, particularly with regard to the real chemical nature of the products.

The qualities expected to be found in a covering film are listed below as a conclusion. The authors remain at the reader's disposal (if by chance they are confronted with selection problems) and are ready to provide them with any additional information and above all with greater detail concerning the exact properties of the products marketed.

A single or double covering material whether to be used permanently or temporarily (as thermal screen) will be rated as good if:

- it affords economical use, which does not necessarily mean the lowest buying cost;
- its life span matches that claimed by the supplier;
- it offers maximum transparency to solar radiation, mainly to the so-called "visible" or the photosynthetically active one;
- it retains the largest possible amount of far infrared, i.e. the heat re-emitted by the ground and the plants within the greenhouse after they have absorbed the incident solar radiation (in other words, the material must be made so as to allow the greenhouse effect to be at its fullest). This means that the PE (polyethylene) films must contain various far infrared-absorbing substances (charges);
- it prevents the heat kept as previously explained from escaping from the greenhouse. This means that the coefficient of thermal conductivity "k" must be the lowest possible. It is worth recalling that the value of "k" is linked to the climatic characteristics of the region where it is measured or calculated. Therefore, the values recorded by producers in different conditions cannot possibly be compared;
- it does not collect dust or at least it must be easy to wash (with pure water or with a solution of oxalic acid 6%), otherwise the properties of transparency to light risk being reduced drastically (i.e. it must be "anti-static");

- it avoids the formation of separate large drops on the inward face of the covering material when the water contained in the air of the greenhouse condenses (such drops fall onto plants very easily), but favours condensation in the form of a continuous thin film which enhances the thermal properties of the PE film) and is collected on the sides instead of falling on to the plants. Inclusion of an anti-condensation ('anti-drop') agent is often necessary.

Unfortunately, not all the materials offered on the market combine the characteristics mentioned above. They are even far from it.

A way to fight against exaggerated propaganda and counter-truth is to have valid products sanctioned by a quality mark (label) issued by a national or international institution of undoubted objectivity.

For many years, the French Committee for Plastics in Agriculture has been controlling an official "PF" certification for plastic films used in agriculture and the Italian Institute for Plastics, through AMPA (Italian Association for the Applications of Plastics in Agriculture), has just reconsidered the norms (UNI 7742 and 7743) and created an identification mark (IIP).

Such examples are well worth applying in all producing countries.

3.1.3.3 Reactions of plants towards the covering material

It goes without saying that plants "react" to the nature of the covering material as a result of the microclimate generated by the latter.

A. Available light

Since most covering materials are hardly coloured or even not at all, the transmission of light is total or nearly so. Quantitatively speaking, the transmittance factor is practically equal whatever the wavelength of the visible; this creates no disequilibrium of the solar spectrum - provided the latter can be held as "balanced".

In the less sunny parts of the Mediterranean region (southern Europe, north of western Africa) - cf. § 4.1.2 "Light" - or when lighting is weaker (during winter time), the influence on plants of any reduction of light is to be avoided whether the reduction is due to a material used alone as covering material or to the use of plastics as lining material. However, one must not confuse the hardly perceivable reaction of a plant towards a few percent decrease in available light due to the use of a less transparent material (e.g. thermal PE : 87% compared to "ordinary" PE : 92%) and the actual etiolation or the slowing down of growth due to the use of a second plastic film to line the greenhouse with a view to creating a thermal screen - mainly if the work has not been properly performed (minimum reduction in available light: 10 to 15%).

B. Thermal balance

If one is satisfied that the rate of growth of plants within a greenhouse is in a way proportional to the inside temperature - provided the light balance is positive - then the "insulating" single wall materials such as IR-PE's or thermal PE's are likely to favour more abundant and/or earlier crops there and when temperature is a limiting factor (winter in the northern and western parts of the Mediterranean region). The proportionality factor is linked to the requirements and to the nature of the plants. It is however, complex to determine. Experiments have been and are still being carried out in the Mediterranean region where heat (and) or light are limiting factors some time during the year.(*) Elaboration would suppose a lengthy work and, seeing how diverse they are, they would be hard to summarize.

In the sunniest parts of the Mediterranean region, and everywhere in the same region whenever excess insolation generates damaging temperatures inside the greenhouse, shading is useful - at least for a time during the year or during the day. Considerable research is being conducted in this field. Of course it would be profitable for the grower to change - even partly - the greenhouse cover for shading or to combine both of them. Theoretical results prove highly interesting but the costs are still prohibitive (cf. 4.1.1.2 "Shading"). Anyway, "shade covers" over nurseries always return profit.

3.1.4 FASTENING AND STRETCHING OF FILMS ON GREENHOUSES

3.1.4.1 Fastening of the films

Film fastening should be devised so as to "mobilize" a minimum of labour over the shortest possible time. Removal should also be a quick operation. Stretching must be tight so as to avoid fluttering.

In the case of wooden constructions, the film is generally sandwiched between the frame and the ledges nailed to it. This is a costly and labour-demanding method. The film is stretched over the wooden construction and, then, wooden ledges are nailed together with the film on the construction. If possible, one should avoid fastening the film by nailing.

To avoid any tearing being initiated, the film must be fixed without discontinuity. It must be covered by soil all along the sides; or special devices should be used (profiles or clips).

Different types of plastic, aluminium and steel fastening devices are being offered on the market (Fig. 46). All of them have been studied to accelerate fastening and removal.

(*) Several authors - 1984 - ACTA HORTICULTURAE 154 - Second International Symposium on Plastics in Mediterranean Countries. - Hammamet (Tunisia)

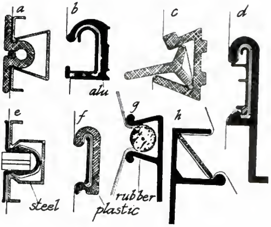

Fig. 46: Some film fastening devices

The existing fastening devices fall into one of the following categories:

- **"one-way" devices:** films can only be drawn from one side towards the other, or else the device opens (Fig. 46 : b,c,d,f,h).
- **"two way" devices:** films can be drawn from either side towards the other (Fig. 46 : a,e,g).

Fastening devices are subject to the following demands:

- sharp edges are excluded;
- film assembling has to be done rapidly and without any cutting tools;
- the possibility of fastening two films must be provided.

A very good solution is the combination of the fastening device and the gutter (Fig. 47). Either the fastening element is an integral part of the gutter (a) or the edge of the gutter is designed so that the film can be rolled up round a pipe and fixed in the bow of the gutter (b).

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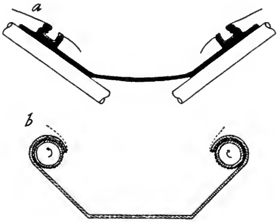

Fig. 47: Combination of the fastening device and the gutter.

Figures 19 and 20 show a round-arched steel pipe greenhouse from Cyprus with such a fastening device at the gutter.

Fig. 48 shows a steel profile of a greenhouse construction which is at the same time a fastening device. The film is fastened by cut pieces of plastic pipe.

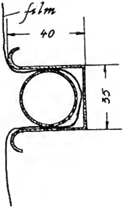

Fig. 48: Fastening by cut pieces of plastic pipe in a steel profile

Yet another type of special plastic profile is shown in Fig. 49, below. This plastic profile is fixed on the greenhouse construction every two metres from the ridge to the gutter. Single or double plastic film is laid around a plastic chord. This chord is drawn together with the film through the profile, for example, from the gutter over the ridge to the gutter on the other side. This system provides good stability and allows fast repair of any damage caused to the film between 2 trusses.

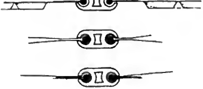

Fig. 49: Special plastic profile for film-fastening.

Some other fastening systems, integrated with the greenhouse construction, are described in paragraph 3.1.1. For instance, the system that does not require nailing - known in southern Portugal - and the Spanish one (film inserted in between two nets; Parral). But the latter system has to be installed by experts very correctly. Otherwise, it will allow the film to flutter in the wind and to deteriorate (see § 3.1.1).

In some countries the plastic film is fastened and stretched by digging it into the soil along both sides of the construction. Farmers dig a ditch along both sides of the construction, stretch the film over it, lay the film in the ditch, and cover it with soil.

3.1.4.2 Stretching plastic films

Plastic film can be stretched in different ways after it has been fastened:

- using the fastening device itself;
- using plastic ropes, stretched over the film;
- using fibre-glass bars;
- using a mechanical device (Fig. 50).

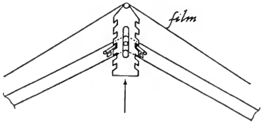

Fig. 50: Stretching the film by means of a mechanical device

- rolling the film around a pipe in the gutter (Fig. 47);
- inflating a double film with air;
- using an inflated plastic tube (Fig. 51);
- using pressure inside the greenhouse.

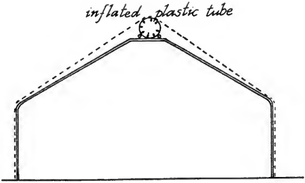

Fig. 51: Stretching by means of an inflated plastic tube

Double films (inflated double skin) at an internal pressure of 50 to 60 Pascal, offer good resistance to wind forces and have a good thermal insulating effect. A **single film** can be stretched by means of an air-inflated plastic tube up to a pressure of 350 to 900 Pascal (35 - 90 mm water). (See Fig. 51).

Both fastening and stretching the film are very important for the durability of the film cover and the construction itself. Increased investments in the construction itself are bound to result in safer plant production and lower labour costs.

In order to avoid the film being destroyed prematurely, it must neither flutter nor over-heat through contact with the construction's metallic parts. The tubular parts on which the film rests should be such that the film does not become overheated in the sun. The upper sides of the tubes can either be painted white (the sun thereby being reflected more efficiently) or strips of insulating material stuck onto the tubes. A further possibility might be to cut open synthetic hose material and wedge it over the metallic tubes.

3.1.5 PROPOSALS FOR QUALITY STANDARDS

Proposals for standardization of greenhouses in the Mediterranean region should consider:

1. the construction;
2. the covering material;
3. standards for wind loads.

3.1.5.1. Construction

This subject has already been dealt with in chapter 3.1.1 and 3.1.2.

- The **resistance to wind** is influenced not only by the quality of the construction but also by the way the covering material is fastened and stretched: fluttering and nails are to be banned; nets are not very suitable in some countries.

- Sufficient ventilation will not be achieved in multispan greenhouses ventilated only through side-walls unless they are under 25 m wide. Side-wall ventilation is the only economical one for plastic-covered greenhouses. Roof ventilation is too costly for multispan greenhouses. Forced ventilation needs a relatively high amount of electricity (see § 3.1.2).

- **Gutters** should be used for collecting rainwater as well as for fastening the film and are an integral part of the construction.

- The **simple basic construction** proposed in chapter 3.1.1 can be made up of wood or steel trusses depending on the price of materials. The independent roof construction, to be laid on the basic construction, is of steel or wood, depending also on the price of materials (Fig. 15, chapter 3.1.1).

- **Wooden constructions** are of the saddle-roof type (see Fig. 10).

Steel constructions should be built as round-arched or pointed-arched constructions, since these are more suitable for plastic film covering.

3.1.5.2. Covering material

Covering materials and their properties are described in chapter 3.1.3. In most cases plastic films are used and the following requirements are worth stipulating:

- the plastic film should last on the structure for at least one year;
- it should be as transparent as possible to solar radiation (360-2 500 nm)
- it must absorb a maximum of long wave radiation at wavelengths between 5 000 and 30 000 nm;
- it should have 'anti-drop' qualities. This means that no drops should form on the inner surface of the covering material; the condensation should run down as a water film, as it does on glass. This requirement also applies to rigid plastic materials.

Note: Double inflated plastic films have good insulation properties besides offering the best resistance to wind forces.

The durability of a film is linked to the way it has been stretched and fixed as well as to the solar radiation to which it is exposed. One year seems the minimum durability expected, but a longer duration is often preferred (up to 3 years). It must be kept in mind that the quality varies widely between countries and that no unique standards can possibly be drawn; for instance, if a film is expected to last for three years, its composition will be submitted to much more drastic requirements if it is to be exposed to strong sunshine than if it is to be used in countries with low insolation. Each country has to establish its own standards.

3.1.5.3 Normalization of wind loads

Some countries have standards and requirements for greenhouse structures (France, The Netherlands, W. Germany) and quality control for plastics (France, Italy, Spain). Wind forces in terms of both greenhouses affect pressure and suction forces. With wind direction perpendicular to the greenhouse ridge, suction forces normally apply to the lee side and pressure forces to the windward side. The wind forces are calculated by the dynamic pressure q, depending on wind speed and height of the greenhouse, and by a coefficient c, depending on the building and roof construction. The wind force becomes:

$$F_W = c \times q \qquad 3.1.5\text{-}(1)$$

The dynamic pressures (q) to be assumed for plastic-covered greenhouses vary in France from 350 to 450 Pascal, depending on the region. These figures correspond to a wind speed of 24 to 28 m/s. In Germany the dynamic pressure varies from 250 to 500 Pascal, depending on the height of the building from less than 4 m to up to 8 m. These figures correspond to a wind speed of 20.4 to 28.3 m/s.

The coefficients (c) differ from country to country. There are positive and negative figures, so that greenhouses have to be protected from pressure and suction forces.

For example the following greenhouse standards exist:

France

NF 57-063 (March 1983) for round-arched greenhouses with plastic-film covering
NF 57-064 (March 1983) Multispan greenhouses.

W. Germany

DIN 11535 (1974) Greenhouses
DIN 1055 (1975) Loads for buildings.

Belgium

NBN 894 (1971) Covering materials for greenhouses.
NBN 15-001 (1977) Natural illumination of glasshouses.

Italy

UNI 6781-71 (1971) Greenhouses with metallic structures.

The Netherlands

NEN 3859 (1978) Glasshouses.

3.2 LOW TUNNELS AND FLAT FILMS

Low tunnels belong to the most revolutionary developments introduced in the last 30 years in commercial horticulture. The countries which widely adopted low tunnels are Japan, USA, France, Italy, Spain, Greece, etc.

Cultivation in tunnels is usually termed "semi-forcing", reflecting its position midway between open-air growing and protected growing in greenhouses. Low tunnels constitute a reasonably low cost method of intensifying production. They are used to accelerate plant growth, to increase production and to improve the quality of the products.

The first low covers appeared in France in the 17th century and were glass bells. Plastic-covered low tunnels were constructed for the first time in 1950 in Japan. In 1959 Faust patented a horticultural cloche of permeable plastic material consisting of arch-shaped frames covered with a plastic film. Low tunnels spread widely after 1960.

The main advantages of low tunnels as compared to greenhouses are: low cost, ease of construction and mechanization of the application of construction. The most important disadvantages are associated with difficulties of heating, ventilation and care of the plants.

One of the characteristics of most countries which have "converted" to plasticulture is the adoption of low tunnels prior to "walk-in" tunnels or greenhouses, which appear only after growers have got used to the technique and feel they can afford them or when they begin to resent the inconvenience of the former. However, some countries, such as Morocco, Algeria and - to a lesser extent - Spain, have not experienced this transitional phase.

The technique of unsupported plastic sheets (flat films) (UK: direct cover; USA: floating cover) was developed recently in W. Germany and in Belgium and has become accepted under continental climatic conditions for a wide range of applications essentially in the open air. The unsupported plastic sheets offer appreciable advantages such as: simplicity, effectiveness, protection against cold and wind, improvement in the quality and uniformity of crops, protection against birds and greenflies, earliness etc.

3.2.1 STRUCTURE AND EQUIPMENT

Low tunnels can be described as miniature greenhouses. They differ from the latter in that they are generally not heated and are usually portable. However great the importance of low tunnels is to growers in some regions, only limited attention has been given by research workers to solving the problems associated with their construction and environmental control.

Many types of tunnels, with or without a supporting structure, have been developed. The traditional frame of tunnels usually consists of a wooden or metal framework of semicircular cross-section, covered on top with a plastic film. The supporting framework may be formed of wood, wire, plastic-coated wire, PVC or metalic tubing, placed at intervals of 2-3m. In Japan, tunnels have been supported on bent bamboo canes. Tunnels supported on metal hoops made their appearance in 1956.

The most important types of tunnels developed in different countries are the following:

a) **Nantes tunnel**. This is a tunnel with double hoops originally developed in the French region of Nantes. The framework of the tunnel consists of metallic supporting hoops which are anchored in the soil about 30-40 cm deep. The plastic film is stretched over the hoops and is held near the ground, fastened on loops. In some cases, the edge is buried in the soil. The height of the tunnel is about 40-60 cm while the width is 120 cm. A very interesting development in this tunnel was a system permitting the film to slide between the sets of hoops to allow ventilation. These types of tunnels are cheap to install and maintain, they have good wind resistance and are suitable for strawberries, peppers, eggplants and tomatoes (see Figure 52).

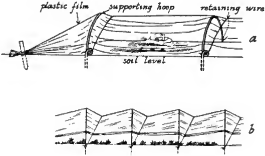

Fig. 52: Nantes type low tunnel. Side view of the tunnel a and plastic film lifted from soil level b

b) A type very similar to the Nantes tunnel but without loops on the hoops has been developed in the USA and in Great Britain. This type of tunnel is 30-40 cm high by 60-90 cm wide and is used for protecting strawberries, melons, salads and beans. The plastic film is fastened by means of a string which is tied on the hoops.

c) Especially for melons and squashes a very small type of tunnel, 30-40 cm high by 40-50 cm wide has been developed and is widely used in the USA, in Israel, in Greece and in some other countries. In this type of tunnel the plastic film is stretched on small metallic hoops and is buried along the sides with soil. For ventilation, holes are opened in the top of the tunnel. The framework and the laying of the film are mechanical. A machine can cover more than 1/2 hectare per 8 hours.

d) The "Californian row cover" system is made up of two plastic sheets unrolled on either side of the row, the lower part being buried and the upper one attached by means of clothes-pegs to one or more wires stretched between poles. Such a system provides progressive openings for tall crops (tomatoes).

e) A double-wall tunnel inflated by means of a fan and supported by air pressure has been tested successfully.

Flat films. The plastic cover acts as a windbreak and protects the plant from low temperatures, wind, hail, rain, birds and insects. This technique leaves the plants under a plastic film until the weather conditions get better. The plants are then uncovered. This type of cover does not need a framework. Ventilation is obtained through holes opened in the film. The flat film technique, which does not involve any support or frames, obviously requires ultra-light materials offering high porosity to air and water, i.e.:

- PE films with 500 to 1 000 holes per m^2 (4-8% of ventilation - 46 g/m^2)
- non-woven films (15-25 g/m^2) which are generally more porous but possess less mechanical strength.

The film is spread over the crop immediately after sowing or planting, and is kept loose enough to allow plants to push it up as they grow. The period for which the cover is maintained on the ground varies with species and season.

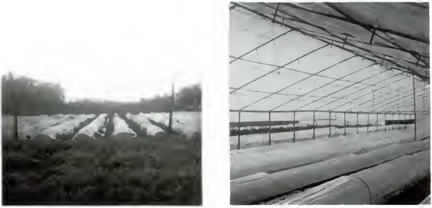

Fig. 53: "Nantes"-type tunnels protected by windbreaks (Morocco) and tunnels built in a glasshouse (Europe)

3.2.2. ENVIRONMENT INSIDE THE TUNNELS

Compared to regular greenhouses, low tunnels contain a much smaller quantity of air, which creates different temperature, light and humidity conditions.

3.2.2.1 Temperature

Air temperature in low tunnels follows a sine-type curve. The temperature inside the tunnel increases during the warmest hours of the day and decreases during the coldest hours. The increase of air temperature inside the tunnels depends mainly on the type of covering and on the intensity of solar radiation. On sunny days the air temperature inside the tunnels increases rapidly. It has been observed that in such conditions when the ambient air temperature is 15°C, the air temperature in polyethylene-covered low tunnels is about 30°C. On cloudy nights, the air temperature in low tunnels is usually 1-3°C higher than the ambient air and during nights with clear sky it is 1-2.5°C lower.

This is the so-called temperature inversion so much dreaded by growers, who often exaggerate its actual danger. Indeed, if this "temperature inversion" means that the temperature is lower inside than outside the tunnel, it does not necessarily involve frost and the resulting destruction of plants. Provided the latter survive and do not undergo irreparable damage, the inconvenience, though real, is limited : the inversion does slow down growth to the disadvantage of the grower.

It may be mentioned that PVC, EVA or modified PE films generally raise night minimums by 1 or 2°C in comparison to the T° observed under PE. Wise cultivation practices (e.g. timely closing of the tunnels in the afternoon) reduce the risks of inversion and lessen its importance.

Low tunnels may also fit into walk-in tunnels and greenhouses as a complementary protection. This is a widely spread technique in Spain. It allows, when winter insolation is sufficient but not excessive and the weather is definitely cold, to keep tunnels closed within the greenhouse. It also raises night minima considerably (2 or 3°C or even more) if insolation is not sufficient.

Low tunnels are not usually heated. Some research workers have tried to heat them by means of electricity, warm water circulation or by laying inside the tunnels tubes filled with water and asphalt blocks intended to absorb heat from solar radiation in daytime and to release it during the night.

Ventilation remains the most serious problem. Efficiency must be reached within the shortest possible time and without endangering the shelter's resistance to wind. Cultivation requirements vary considerably within the Mediterranean region: in the north and northwest, tunnels are opened only when insolation is sufficient and the degree of opening is linked to the degree of insolation. Down to the south, the tunnels are kept open over longer periods of the day and sometimes during the night, and are closed only to offer protection from gales.

Similarly, the use of perforated films is linked with latitude. Covering of the tunnels with perforated plastic films gives some interesting advantages such as: sufficient control of air temperature and moisture condensation, less labour for ventilation, high resistance to winds etc. The main disadvantage of using perforated films is the loss of earliness. Research has shown that adequate ventilation of the low tunnels has been obtained by using perforated films (1000 holes 1.5 cm in diameter per m² = approximately 20%). In very warm weather conditions it has been found beneficial to enlarge the holes (aeration >20%). The number or the size of perforations and their location (on the side or along the ridge of the tunnel) obviously condition the degree of efficiency.

There exists no "Mediterranean" solution: every region must find the technique which best suits its climate, and the number, diameter and the location of perforations must be adapted accordingly.

Ventilation is carried out manually and is therefore labour consuming. It consists in raising the film slightly on the lee side (see above). It is advisable to operate during the late hours of the morning (10 a.m. in winter) so as to allow crops to take advantage of the temperature rise resulting from the insolation of the early hours. The film must be lowered early in the afternoon (round 3 p.m. in winter) to keep the heat accumulated for the night.

The decision to open and to close the tunnel must be made every day. It presupposes understanding on the part of the grower and a sustained effort on the part of advisers. Indeed, when the sky is overcast, opening occurs later. Ventilation may even prove useless in certain climates.

A simple and effective way to ventilate low tunnels was developed in Greece. According to this, ventilation openings are made along the top of the tunnel by tearing the plastic film. In warm weather conditions the openings become wider and air movement takes place.

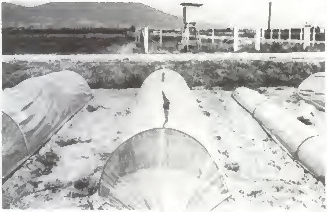

Fig. 54: A simple system for ventilating the low tunnels

3.2.2.2 Light

Low tunnels, due to their shape, usually have good light transmission. Moisture condensation and dust sometimes reduce light transmissivity in low tunnels. However, light conditions in low tunnels are improved by using more transparent plastic covers, by ensuring good ventilation, by washing out dust (when possible) and by locating tunnels in shaded situations (near trees and hills). In the southern part of the Mediterranean region films are apt to be used for two years provided the crop does not require too much light (squash).

3.2.2.3 Humidity

In low tunnels with inadequate ventilation or in those ventilated only during daytime, relative humidity increases above the desired level and moisture condensation on the plastic films and on the plant is a common occurrence. High relative humidity of the air in low tunnels does not normally cause trouble in late spring and summer (sometimes it is advantageous, but could be a problem for autumn and winter crops). In tunnels covered with a perforated plastic film there is usually no problem of high relative humidity, but in tunnels without perforations there are dangers of disease and infection of plants.

3.2.3 THE USE OF LOW TUNNELS AND UNSUPPORTED FILMS

Beneficial results have been obtained with low tunnels and unsupported films on many kinds of crops and in several countries. The micro-climate created under tunnels encourages good development of roots, better photosynthesis of plants with effects on earliness, quality and productivity. Earliness and quality are reflected in an increase of the financial returns.

It has been found that low tunnels protect plants from low temperatures, wind, rain, hail, birds and insects. It is well known in practice that the first sowings and plantings in spring are often attacked by birds and the covering provides effective protection. Furthermore, provided low tunnels are not more than 2-3 m apart, they act as windbreaks for crops grown between the covered rows.

Very humid conditions obtained in unventilated tunnels increase the incidence of fungal diseases and can be responsible for poor setting of strawberries, tomatoes and melons, resulting in misshapen fruit.

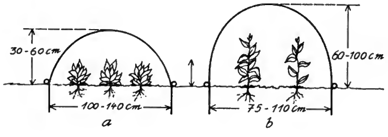

Fig. 55: Low tunnel to cover low-growing (a) and tall plants (b)

Low tunnels can also be used as a nursery for young plants, from sowing to planting in the open air.

Low tunnels are more suitable to protect low-growing plants such as strawberries, melons, squashes and salads during part of the growing period. In some regions "determinate" tomatoes ("self-pruning") are placed under low tunnels for some months.

Plants such as melons, tomatoes, peppers, eggplants are transplanted into low tunnels 2 or 3 weeks earlier than they would be if they were transplanted outdoors. Compared to outdoor production, earliness under tunnels gains 10 to 25 days.

The following figures are an illustration of improved earliness for flat film production under average Mediterranean conditions; salads: 8 to 10 days; radishes: 15 days; potatoes: 15 to 20 days.

Although some small growers still use one tunnel to cover two crops in the same year, in most cases tunnels serve only once.

Some points of interest merit particular attention as far as the practical application of the system of low tunnels is concerned.

- **Thickness of PE films:** as long as the region is not submitted to particularly strong winds, 60-80 micron PE films will do perfectly. The price of the film varies with thickness, and horticulturists feel strongly about this basic investment that they sometimes consider as a burden. About 1,000 kg of film are needed to cover one ha with a 100 micron PE film whereas only ± 600 kg will suffice if the film is 60 microns thick. A thickness of 60-80 microns ensures enough resistance. Actually, it is the distance between hoops which determines the resistance to wind: 75 cm in windswept regions, up to 2 m in sheltered places. P-PVC and EVA require particular care, as any excessive elasticity may cause "pockets".

- **Annual use:** for reasons of transparency to light it is often advised to limit the use of a film to one year. However, a soiled film is perfectly suitable for mulching (with or without application of weed-killers) or as bottom cover for the "sequias" (Arab word for any open air furrow, gutter or channel intended to drain water).

- **Width of the tunnel:** the width of the tunnel and consequently of the film deserves some consideration. The temperature of a large volume of air undergoes slower changes than that of a small volume: this generates a kind of thermal reserve. This has encouraged growers in Tunisia and in some other countries to use 2-m-wide films; "Crops are allotted more space in wider tunnels, the protection is likely to last longer and the use of the ground is more intensive. As a matter of fact, a 2-m-wide film provides a larger ground surface which allows two or three-row planting and - why not - irrigation from within the tunnel instead of beside"(*).

- **Galvanized iron wire:** for long tunnels (80-100 m) galvanized iron wire No. 22 J.D.P. (= Jauge de Paris : French wire-gauge) measuring 5.4 mm in diameter is to be preferred to No. 18 (3.4 mm in diameter) - smooth concrete wiring is also useful and can be found everywhere. In windswept countries, the Tunisian technique proves interesting. It consists in reinforcing the resistance at both ends of the tunnel by means of wire No. 25 (about 6 mm in diameter). (*)

- **Hoops:** to maintain 2-m-wide plastic films, the hoops are prepared as follows:

  1. iron wire is cut into 2.5-metre long sections;
  2. loops of 3 cm in diameter are shaped about 20 cm from either end;
  3. the wire is bent round a gauge to form a semicircle. The guage is made up of poles firmly fixed in the ground.

(*) L. TABRESSE et al. (1982) : Cultures maraîchères au Sahel Tunisien.
AGCD. 5, Place du Champs de Mars, Brussels.

- **Fixing wires:** the hoops are supported and held at a constant distance from each other by means of fixing wires (the hoops are interlinked and bound to the poles driven at the two ends of the tunnel). Interlocking is carried out prior to film laying. The fixing wire is a piece of ordinary string or galvanized wire No. 6 or plastic string. It must be strong and durable (polypropylene agricultural string, resistant and cheap).

- **Retaining wire:** stretching wire is used to maintain the plastic film over the hoops. Fixed on either side of the hoops, it joins the two loops of one same hoop or zigzags from one loop to the opposite one in the following hoop. Plastic or plastic coated material is advisable because it is more solid and therefore more durable.

- **Spacing:** intervals between consecutive hoops depend on the diameter of the hoop wire. If wire No. 22 (5.4 mm diameter) is used, 2 metres is a maximum (see also "thickness of film", above).

- **Stretching of film:** the film must be laid when the temperature is fairly low and it must be stretched tightly. The life and efficiency of the film together with ventilation facilities depend on good stretching.

- **Airtightness:** when the tunnel is closed (at night), it must be airtight. This means that both sides of the film must run along the ground. Keep an eye on tightness, particularly when "closing" tunnels at night.

- **Mechanical laying:** tractor-driven machines have been devised to cover tunnels and unroll mulching films.

- **Orientation of tunnels:** this point is of paramount importance. The risk of the film tearing or lifting up from the ground is lessened if the tunnel is perfectly airtight and has been laid perpendicular to prevailing winds. Slightly raising the film on the lee side ensures ventilation whilst maintaining the "windbreak" effect.

- **Pre-heating:** in relatively cold climates tunnels must be erected at least one week before planting. The soil must be irrigated and ventilation must be avoided. All this will make for pre-heating of the shelter and provides the soil with the temperature required by the plants.

- **Irrigation:** this is no easy task when the tunnel has not been carefully designed. Wider tunnels accept two- or three-row planting with irrigation drains in between the rows and sometimes even under the mulching film. However, if the in-flows are too strong or too weak, the tunnels have to be opened and the ground cultivated in order to keep the irrigation furrow in working order. In practice, furrow irrigation under tunnels is still haphazard, hence the need for a proper irrigation system (localized irrigation or perforated pipes), particularly when a mulching film is being used (cultivation in double rows with drip irrigation pipes between). Anyway, irrigation within the tunnel is worthwhile since it keeps the ground in between the shelters in a dry condition.

- **Investments:** the current price per ha in Tunisia may be put at about 1 500 - 1 600 TD. (US dollar 0.2 - 0.3 per square metre). Naturally, it depends on the local prices and the nature of the material used.

3.3 MULCHING

Mulch can be defined as any substance such as hay, sawdust, corn shucks, wheat straw, plastic sheets, spread on the ground to protect the roots of plants from heat, cold or drought, or to keep the fruit clean (strawberry).

Mulching plants to improve growing conditions is a practice that dates back 300 years or more. Plant residues and animal manure were the first mulching materials to be used. During the late 1920's and early 1930's ashphalt and kraft paper were extensively used in the USA. Mulching developed noticeably after 1950 when polyethylene film became available.

The year 1955 marks the beginning of the development of the three techniques that use plastic films in horticulture (mulching, low tunnels and greenhouses) in Europe between the 47th and the 52nd degrees of latitude. It soon appeared that the region best located to benefit by these newly created materials corresponded in all probability to more sunny climate zones.

The three techniques rapidly invaded the southernmost areas and it is interesting to note that each of them has claimed its own territorial share:

- the **greenhouses** were quick to spread over the entire Mediterranean area and far into Africa and the Middle East;
- the only place that the **low tunnels** attempted to break into is south of the Mediterranean, where they are however few and far between, except in Tunisia, where they have really been adopted;
- plastic **mulching** did not find a favoured ground along the Mediterranean nor south of it. Though results of research conducted in the different regions of the Mediterranean zone have indicated that this technique has every chance of success there, so far, the Mediterranean horticulturist has not really felt attracted.

One explanation is the Mediterranean climate itself, but sociological and above all economic factors (difficulty in getting valuable material, cost of material) have most probably contributed to further minimize an interest that the horticulturist already considered insufficient from the start.

In the following paragraphs, which focus on mulching, the latitude of the region involved is an important matter in that the very nature of the material (in this case a plastic one) likely to prove successful is closely linked to the climate characteristics (temperature, insolation) and to the edaphic ones (humus, salinity) of the region. The tremendous development of the "enarenados" (cf. par. 5.1.1) in southern Spain confirms, for sand or gravel mulch, what has just been stated for plastics.

3.3.1 MULCH MATERIALS

Mulches may be grouped into natural materials and man-made artificial products.

The natural materials include wood products (such as chips, sawdust), peat, animal manures and plant residues such as hay, straw, composts. Manure can be mixed with sand to improve the technique (cf. 5.1.2). Generally, they improve infiltration of water into the soil, help to maintain a uniform soil moisture level, return organic matter and plant nutrients to the soil, improve soil tilth as they decompose, reduce surface evaporation of water, aid weed control and increase the organic matter content of the soil. The principal disadvantages of using natural materials as a mulch are: handling difficulties, in some cases they maintain relatively low soil temperatures, and some materials such as straw may contain seeds which increase the weed population.

The **man-made** (artificial) **materials** include paper, plastic sheets, paper-plastic combinations, aluminium foils and asphalt spray emulsion. All these materials have been used with different degrees of success. These mulches are easily adapted to mechanization, they may be produced in quantity at low cost and they may be designed for individual crops.

Paper has been found effective as mulching material, but it is too costly and fragile; it often deteriorates and becomes useless before the season is over. Colour and thickness are important since the paper must not transmit a significant amount of light.
Machine application of paper mulch is as troublefree as laying plastic mulch. Paper mulch has the advantage of being biodegradable and it decomposes when plowed in. Kraft mulching paper is resistant to fungal attack and has wet-strength properties.
Plastic films are easily applied mechanically, are inexpensive, conserve moisture and in many cases control weeds. The serious limitation of plastic films is that they do not decompose and must be removed at the end of the crop season, otherwise the film remains in the soil. Among the different kinds of plastic films, transparent and black polyethylene are the most frequent. They offer the best results for the lowest costs. Thin plastic coatings of paper combine the advantages of plastic films with the advantages of paper (decomposition and disposal into the ground).
Aluminium foils are also interesting mulching materials which reflect solar radiation, increase light for plant growth, and are reported to repel certain harmful insects.
Asphalt emulsion is sprayed directly over the row to increase soil temperature, but formulation, application, weed control and rapid breakdown with rainfall pose some problems.
Other mulching materials which are under test or have found recent applications are the photodegradable films, the thermal and 'nondrop' ones, light-absorbing ones etc... Although some natural mulching materials continue to be used by home gardeners, plastic films are widely accepted in commercial horticulture.

Using organic and synthetic row mulches

The field to be mulched should be ploughed, fertilized and prepared in the normal way. Mulch should be applied when soil conditions permit, i.e., when neither too dry nor too wet. Early mulch application has the advantage of warming the soil prior to planting.

The **organic mulching** materials are usually spread around the established plants when they are 10-15 cm tall. Some organic mulching materials such as wheat straw and hay contain weed seeds and are naturally low in nitrogen: they consume most of the nitrogen contained in the soil as they decompose, thereby imposing the necessity of applying additional fertilizers. Natural mulch materials require considerable hand labour, because usually they cannot be spread mechanically.

To place the **synthetic mulches** over the row a shallow depression is dug on each side of the trench about 25 cm from the centre of the row. The plastic film is pulled tight and the edges are covered with loose soil to hold it in place. In very rainy areas, it is advisable to sow along the top of the ridges in order to prevent asphyxiation of the root system. Row mulching is sometimes to be preferred to total covering of the cropped area. In that case, the unmulched zones between rows are to be cultivated or treated with herbicides to control weeds. Since sowing and planting are almost inevitably manual activities and thus labour demanding, this technique applies only to crops expected to return large profits. Several machines have been devised to lay plastic mulches.

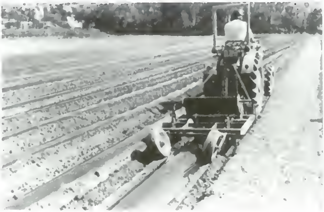

Fig. 56: Application of plastic mulch by a tractor

Some of these machines can be adjusted to lay any width between 60 and 180 cm. The film can be set in place either before or after planting. In either case the perforation needed for the young plants to grow through the film can be done either by means of a sharp tool or of a butane-heated punch. Experience shows that the effects of mulch are linked to some extent to the width of the strip.

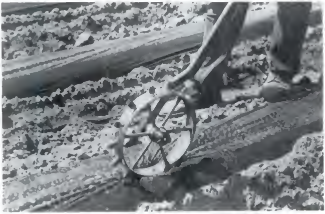

Fig. 57: Hand-operated machine having a toothed wheel to make holes in plastic films.

When plastic films are laid down after transplanting, the perforations are opened when the frost danger is over and before a high temperature rise under the mulch can kill the plants.

3.3.2 INFLUENCE OF MULCHING

Mulch changes the plant environment significantly and influences crop development during the periods when growing conditions are less favourable. It may help alleviate plant stresses caused by poor rainfall and low air and soil temperatures. Mulch also helps to control weeds, evaporation, soil compaction, leaching, etc.

3.3.2.1 Moisture

Mulches generally reduce the evaporation of water from the soil and save water by reducing competition from weeds. Organic mulches increase the rate of rainfall absorption by the soil. If the soil is mulched with transparent plastic sheets, more evaporation occurs due to the increase in soil temperatures. Although mulches save water, they are not a substitute for irrigation. In some Mediterranean conditions, an additional irrigation system is essential to obtain good results. Soil mulching with black PE film is widely applied in greenhouses to avoid problems of high air moisture.

3.3.2.2 Temperature

Mulching modifies soil and air temperatures near plants. Materials animal manure and straw insulate the soil surface from heat gain and loss, resulting in a uniformly low soil temperature throughout the growing season. On the contrary, plastic sheets can increase the temperature of both soil and air in the immediate vicinity of plants. The type and the colour of the plastic influence soil temperature significantly. Transparent films transmit the sun's rays to the soil, then hold the heat by retarding its escape.

During daytime the soil temperature under black polyethylene mulch is much the same as in uncovered soil, but at night the covered soil is 2-3°C warmer, because of the absorption of the soil radiation. In some Mediterranean regions the temperature of the surface of the soil and the air temperature under the cover can exceed 60°C, causing adverse effects on plant growth.

In some other conditions the plants set on plastic are more likely to be damaged by low temperatures and frost, because the soil heat is kept by the mulch. Under **transparent plastic** cover, the radiation converts to heat energy upon being absorbed by the soil surface, resulting in a very efficient heat build-up. Under **black plastic** cover, much of the heat is lost to the atmosphere rather than to the soil. The type of plastic cover has a significant effect on soil temperature. The temperature of soils mulched with P-PVC and EVA films is usually 2-3°C higher than that of those covered with transparent polyethylene films due to the absorption of longwave radiation. However, such P-PVC and EVA films have hardly ever been used as mulch elsewhere than in research stations.

In some cases (nights with clear sky) the frost ruins plants mulched with black polyethylene films, but does not damage those on transparent PE films. This can happen because the soil under transparent film is warmer and because a black cover cuts down the long wave soil radiation. The temperature of the soil under clear polyethylene films fluctuates a great deal whereas black films keep the range between maximum and minimum within a limited scope especially by raising the latter (black films maintain a fairly narrow temperature range).

3.3.2.3 Weed control

Mulches eliminate most of the labour required to control weeds. The use of a tractor cultivator or a hoe not only damages plant roots and injures foliage but also destroys part of the yield. These hazards to tender crops are largely eliminated by mulching. The colour of the plastic cover greatly influences weed development.

Although opaque films prevent the penetration of the light necessary for the development of weeds, clear films do not and, therefore, herbicides prove a necessity. However, high ambient temperatures (28-30°C) destroy the weeds under transparent films provided these do not allow air leakage.

The very recent use of linear PE - particularly resistant to perforations - has revealed that even perennial species as vigorous as Cyperus esculentus cannot possibly pierce through it in the way they do through ordinary PE. Indeed, they remain confined under the mulch and after a time, the roots get destroyed by solarization.

3.3.2.4 CO_2 concentration

Experiments carried out in the USA and in France have shown that the CO_2 concentration in the air surrounding the plastic-mulched plants is 2 to 6 times as high as that around non-mulched ones. This phenomenon is the result of the production of CO_2 linked to the decomposition of organic materials in the soil and of its concentration around the plants as it moves upwards from under the film through the holes. This is yet another reason why plastic-mulched plants have a better growth record. (cf. § 4.4.4).

3.3.2.5 Light

Photometric measurements of the reflected light above different materials give the following figures:

- above uncovered soil : 20%
- above black plastic film : 4%
- above transparent polyethylene films : 48%
- above metallized plastic sheets : 79%

Moreover, the reflection of solar radiation on metallized plastic repulses aphids while attracting bees.

3.3.2.6 Soil structure

Soil mulching helps to maintain good soil structure by preventing soil crusting and compaction. Mulched soils remain porous, loose, and friable with good aeration. All this contributes to a healthier root system and to more efficient use of nutrients. As a result of well-aerated soil conditions, the biological activity of the soil microorganisms is increased. Mulches are to be spread exclusively over soils that dry out well, otherwise the film is certain to retain humidity, which will undoubtedly increase the risks of asphyxiation of the roots. Mulches prevent heavy rains or irrigation from causing deterioration of the soil structure. They allow water to penetrate readily. Organic mulches return organic matter and plant nutrients to the soil and improve soil tilth as they decompose, but require additional nitrogen fertilizers to prevent nitrogen shortages.

3.3.2.7 Plant production

Mulching affects quality, yield and time of production. Higher temperatures, better moisture and light conditions, higher CO_2 concentration and better soil structure all contribute to improved growth of plants.

Plastic-mulching proves beneficial to crops that are shallow rooted and/or whose roots benefit from higher temperatures, higher soil oxygen or abundant moisture in the surface soil. Cucurbits show more response to mulching than any other crop. In tomatoes, the roots turn downwards and soon fill the soil on all sides of the plant down to 60 cm or deeper. On the other hand, cucurbits have a very extensive well-branched root system that spreads laterally throughout the surface not deeper than 10-20 cm, with very few important roots going deeper than 40-50 cm.

Mulching gives the best results where the soil is poor and sandy, the temperature is normal and the rainfall is low, provided the soil is properly irrigated. It increases the soil temperature and therefore activates the growth of plants.

Many experiments have been conducted in different countries to find the effect of mulching on plant production. Table 12 shows the effects of mulching on earliness and on plant production.

Table 12 The effect of polyethylene mulching in the North of France on different crops (after LEMAIRE, Angers, cited by GRAFIADELLIS).

Kind of plant	Earliness (days)	Increase in yield (%)
Tomato	5 - 10	10 - 50
Eggplant	15 - 20	50 -200
Pepper	15	10 - 70
Strawberry	2 - 10	10 - 25
Muskmelon	10 - 15	25 -100

TOMATO: in general, mulching acts on two elements of a tomato crop. It promotes root growth and increases fruit size. As a consequence, production obviously rises. Indeed, mulching hastens production by 5 to 10 days and increases the yield by 10 to 15%. However, production is highest with metallized plastic films.

CUCUMBER: thanks to the increased soil temperature, growth is accelerated. From experiments in Mediterranean conditions, it appears that total production is up by 35-40% while earliness is hastened by 200-250% in the first two weeks. It also appears that plants on black polyethylene mulch are likely to produce larger-sized fruits.

MUSKMELONS and **EGGPLANTS** react better to mulching than many other crops. It was found that mulching muskmelons with transparent polyethylene film promoted earliness by 12-15 days, increased yields by 25-100% and increased the fruit size significantly.

STRAWBERRIES: the fruits are not in direct contact with the soil provided mulches are properly laid, and consequently they are protected from rots. In addition to improving quality, mulching promotes earliness and increases yields considerably.

OTHER CROPS: mulching is also widely used in the forcing of asparagus, grapes, gladiolus (Fig. 58), pepper, etc.

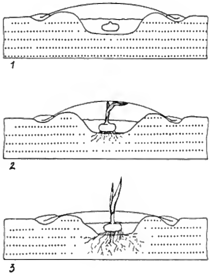

Fig. 58: Mulching gladiolus with clear plastic film.

Some practical comments are worth mentioning:

- A plastic film (cf. § 3.2) sells by weight and its thickness is of no detectable (technical) value except with regard to durability. Therefore, the thinnest film offered on the local market will do, provided its durability and tensile strength prove sufficient. As a rule, 30 to 50 micron films are perfectly suitable, and 80 micron films are reserved for applications where they are supposed to last for more than one year. The thickness is basically determined by the level of tensile strength imposed by mechanical laying: practically speaking, linear PE films should be over 15 microns thick while radicalar ones should be over 25 microns. In China, laying is done by hand (over 1 400 000 ha) therefore films need not be over 9-10 microns thick.

- The width of the film depends on the crop cultivated but should not exceed 0.90 to 1.50 m unless a localized irrigation system has been provided underneath. It should not be overlooked that on both sides of the film, about 10 cm of it have to be covered with soil.

- Pre-perforated films can be used: holes (4-5 mm in diameter) are made throughout the surface of the film or, preferably, only within the limits of a central strip so that rainwater is allowed through, thereby avoiding water build-up and consequent fruit rotting. However, perforated films do not prevent weed growth and do not sell everywhere.

- Black films when opaque enough - i.e. with a satisfactory carbon black content - prevent weeds from developing. They are the most widely used, though the quality offered on some markets is not always up to standard. A better thermal balance is reached through transparent films but weeding is necessary prior to laying.
  A smoke-grey film - intermediary between the two previous ones - was developed but does not look entirely successful.

- The effect of plastic mulching on soil salinity, frequently met in the Mediterranean region, is not sufficiently defined as yet. Experiments carried out on the initiative of FAO show that the reduction in irrigation requirements and in soil evaporation are two phenomena induced by the film which lessen the effects of irrigation with brackish water when furrow irrigation is practiced, black films perform better than transparent ones as they further slow down water movement within the soil and thereby reduce the drawbacks of salt migration, because salt deposits concentrate on those parts of the soil where the plastic is earthed up(*). The constant moisture observed with drip irrigation brings salt essentially around the wet soil bulbs, i.e. between crop rows and at the surface. Consequently, the mulch is expected to play a protective role, preventing rains from carrying these salts down to the root area.

- The same author(*) gives the following practical advice with regard to the stretching of films:

  " - plastic films must not be over-stretched but must be allowed some flexibility so that they can absorb expansion and shrinkage resulting from temperature as well as the shocks they are supposed to undergo throughout the cultivation period;"

(*) J.C. Garnaud (1971) : "Intensification des productions horticoles du bassin méditerranéen par la culture protégée" - FAO - AGPC : Misc/10.

" - black film stretching must be particularly loose. Indeed, they absorb solar radiations, and therefore, they heat up and expand quite a lot during the day, and shrink at night;"

" - films must not be laid during the warmest hours of the day (because of expansion)."

- No satisfactory answer has yet been given to the problems related to the removing of films. With the cultivation period coming to an end, the films get holed, torn, dirty and they are neither easy to recover nor to bury. The only way out at present - until bio- and photodegradable films are offered at a fair price on the market - is to pick up and burn scraps.

- The association of the two techniques - mulching and semi-forcing tunnels - presents advantages that should be emphasized. Various reasons, and in particular labour costs, exclude mulching and above all mulching in combination with low tunnels from many Mediterranean countries. A precise calculation of costs would show for each particular case whether mulching and/or low tunnels will make the increases in yield profitable.

3.4 MISCELLANEOUS

3.4.1 WINDBREAKS

The first windbreaks were seen in regions swept by frequent and violent winds of definite predominating direction. They were supposed to protect the most sensitive plants against the mechanical effects of the wind itself and against the damage caused by wind-driven elements: sand or spindrift. Some of the microclimatic modifications resulting from the reduction of wind-speed are likely to interfere with the behaviour of crops.

3.4.1.1 Physical effects

A. Reduction of wind-speed

Since a windbreak is an obstacle to the wind, it modifies the flow of air around itself. As a result, wind-speed decreases downstream of the windbreak. The effects of a windbreak are essentially linked to its permeability, its height and to the distance that separates the plants from it.

. Impermeable windbreaks (walls, densely planted cypresses, ...) generate whirlwinds that may be responsible for serious damage.

. A permeable windbreak offers protection over a longer distance than an air-proof one.

  - permeable windbreaks are efficient over a distance 10 to 12 times their height;
  - impermeable windbreaks are efficient over a distance 7 to 8 times their height.

. The optimum porosity of artificial windbreaks is about 50% (30% under highly turbulent, blustering winds).

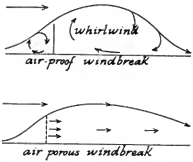

Fig. 59: Effect of permeability of windbreak upon the wind-speed

B. Modification of radiant exchanges

Obviously, during daytime, windbreaks intercept and reflect part of the solar radiation, thereby generating heterogeneous distribution of light. This is complemented by a reduction of losses both at night and during the day. Globally, a windbreak net generates a gain in energy.

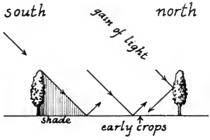

Fig. 60: Effect of windbreak on radiative balance of the plants protected

C. Thermal modifications

The combined effects of the modification of radiant exchanges and of the reduction of air mixing resulting from the decrease in wind-speed lead to an amplification of the variation of temperature at ground level: increase in day temperatures, lesser decrease in night temperatures. Globally, inside a windbreak net, the average temperatures are raised.

D. Hygrometric modifications

The reduction of air movement by windbreaks generates variations in the level of air humidity similar to those recorded in temperatures. During the day the level of humidity goes up while during the night it goes down. Globally, inside a windbreak net, saturation deficits are reduced. The combined effects of the reduction of wind-speed and of the saturation deficit of the air lead to a decrease of the evaporating power of air, hence to an alleviation of water stress.

3.4.1.2 Agronomic effects

A. Protection from damage due to the force of the wind or to wind blown particles

This is certainly the most clearly felt effect of windbreaks, meeting in fact the expectations of most growers. For some particularly sensitive crops (e.g. recently planted material) complete success depends on the presence of windbreaks in the same way as complete failure depends on the absence of the same.

This objective of mechanical protection can be reached provided the space between windbreaks does not exceed 8 to 10 times the height of the windbreaks.

B. Gain in earliness

The increase in temperature behind windbreaks has a positive effect on growth and on rate of crop development, resulting in increased earliness. For those crops which entirely depend on earliness to return profit, windbreaks are fully justifiable.

To derive maximum profit from this "earliness" effect, the space between windbreaks should not exceed 5 to 7 times the height of the windbreaks.

C. Alleviation of water stress

The decrease in evaporating power of air is felt positively by plants as it improves their physiological behaviour. Yet windbreaks seldom reduce the average water consumption of plants very significantly.

Unfortunately, the alleviation of water stress is likely to favour the development of pathogens.

D. Increase of the risks of frost or of shrivelling

When extreme temperatures approach the critical values, the increase in amplitude of their variation may result in more serious damage behind a windbreak than in unsheltered zones.

A sheltered plot will be exposed to greater risks of frost at a distance 3 to 5 times the height of the windbreaks under quite moderate wind. In these conditions, the night temperatures may fall down to 1 to 3°C lower in sheltered than unsheltered plots. When the space between windbreaks does not exceed 5 to 7 times the height of these, there is hardly any risk of aggravation.

The increased risk of shrivelling, which may even lead to tipburn or desiccation of the flower organs, manifests itself only in arid zones under drought conditions. Since intensive cultivations are necessarily well supplied with water, they are not likely to be exposed to these risks.

E. Technical advantages

When crops behind windbreaks are irrigated by means of a sprinkler irrigation system, water is distributed more evenly, provided of course that the sprinklers are chosen and located in accordance with the spacing of the windbreaks.

The role of windbreaks becomes particularly clear when they constitute the only shelter for the crop.

When semi-forcing low tunnels are used, any reduction of strong winds obviously makes it possible to lighten the frame of the shelter (windbreaks with a porosity of 30 to 50% avoid whirlwind damage); besides, when tunnels are open to provide ventilation and the plants are suddenly exposed to the open air, windbreaks alleviate the suffering of young plants not yet acclimatized to wind.

Are windbreaks needed with greenhouses? This depends on the type of greenhouse and on the region.

When the greenhouse is not fitted with artificial heating, the advantages of a windbreak must be compared to its disadvantages to form an idea of the merits that additional protection is supposed to offer.

On the one hand, a windbreak somewhat improves the night thermal balance of the greenhouse. On the other hand, it costs a certain amount of money, it considerably reduces the available light, and it increases the difficulty of achieving sufficient natural ventilation unless the greenhouse is located in a region exposed to strong winds.

But when artificial heating is provided (which often means that the greenhouse is in a cooler region and therefore normally requires less ventilation, a windbreak is more likely to be advantageous. Any protection against wind is a positive way to save the energy needed by heating systems since it reduces heat losses through leaks of non air-tight covering materials. A reduction of wind-speed by $1 m.s^{-1}$ reduces heating needs by about 1.2 $Kcal.h^{-1}.m^{-2}$ for a 1° rise in inside temperature (cf. § 3.1).

Ex: A reduction in wind-speed by $5\ m.s^{-1}$ when the inside temperature of a $1000\text{-}m^2$ greenhouse is 10 degrees higher than the outside one makes it possible to save at least 6 litres of fuel per hour.

Since the windbreak effect decreases with distance, heating needs to increase as one moves away from the windbreak. Thus for crops grown far from windbreaks, more powerful heating equipment is needed. For example in the Rhone Valley, touched by the Mistral - a frequent and violent north-northwesterly wind - if greenhouses are heated by means of a blown air system, the air is blown from north to south.

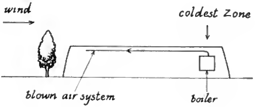

Fig. 61: Position of the blown air system in a shelter protected by a windbreak

3.4.1.3 Types of windbreak

Traditional windbreaks are made of living or dead natural elements. Since the 1960's, plastic manufacturers have endeavoured to devise nets for use as windbreaks.

A. Living windbreaks

These windbreaks are made up of trees fully adapted to the local conditions (eucalyptus, poplar, cypress, casuarina, tamarisk, acacia, sesbania, opuntia, etc.) that reach more than 5 m. They offer protection over 30-80 m. For vegetable crops, secondary windbreaks are often useful.

When these windbreaks are more or less E-W oriented, only the south-exposed side can favour early production, the north one being generally kept for seasonal crops and work paths.

Living windbreaks need care and, in particular, irrigation and fertilization so as not to become a serious competitor to the crops they are supposed to protect. It may prove necessary to control the roots of creeping-rooted trees by means of a sub-soiling plough and the parts above ground by relatively close and regular pruning. It should also be noted that windbreaks serve as a shelter for some animals, insects, pests and diseases.

There also exist annual windbreaks made up of a temporary cultural association, e.g. associations of winter crops - melons or peas - grown in alternate rows, perpendicular to the predominating wind.

B. Inert windbreaks

These are made up of natural elements such as branches or graminaceae stems (phenix palms, arundo canes, ...). Both their height and their protective action are limited. Their main advantages are the utilization of local material, facility of installation, degree of permeability at grower's own will, absence of competition for nutrients with cultivated plants ...

The constituent elements are set side by side deep enough in the ground to withstand wind pressure. Yet it is necessary to reinforce the "palisade" by means of stakes; iron wires, vegetative links, palms, canes, etc. being used to bind all parts together.

C. Artificial windbreaks

The nets proposed as windbreaks are made of woven or extruded cloth and have a guaranteed lifetime of up to 4-5 years provided they are used properly. Anchorage in the ground appears to be the major difficulty. Indeed, since the nets are not inserted into the ground, the pressure is entirely supported by the stakes. Windbreaks over 2-m high can hardly be anchored. Consequently, artificial windbreaks are often used to reinforce the protection for low crops already provided by wide interval natural windbreaks.

3.4.2 HOTBEDS

The use of hotbeds in the Mediterranean vegetable industry dates back centuries. In some regions it is still possible to observe today the tradition of making seedbeds on top of manure piles.

The main advantage of hotbeds is to maintain a suitable soil temperature for seed germination and the growth of young plants. This is important in spring when the soil temperature is rather low for crops with a minimum germination temperature above 12°C e.g., tomato and sweet pepper. In this way it is possible to hasten germination and to increase plant uniformity.

Though hotbeds may be placed in the open, it is preferable to protect them under tunnels or greenhouses. Beds in the open are affected by rain, and heat losses are higher. When protected, the "greenhouse effect" increases the soil temperature mainly during the day and the hotbed is supposed to maintain it throughout the night. Heating requirements are thus reduced.

Hotbeds may be classified according to the source of heat used: hot water pipes, electrical cables or fermentation of organic matter. As the first two are usually very sophisticated and are often used in association with other heating systems, only the last one will be dealt with here.

Many different kinds of organic materials can be used to build a hotbed: cattle manure, leaves, grape residues, etc. However horse manure is preferred, owing to the large amount of heat it releases.

The manure is put in a pile at least 1-m wide and up to 0.8-m high. It is then pressed and watered, layer by layer, with 8 to 10 litres of water per m^2. Pressing and watering are very important as they control the fermentation process and therefore the heat release.

The temperature of the pile starts to rise after 6-7 days, reaching 70-75°C on the 10-11th day and decreasing afterwards: 40°C on the 15th day, 30°C on the 20th, stabilizing between 20 and 30°C during the following month. Thus it is necessary to wait at least 15 days after bed construction before planting the seeds, or they may be damaged by high temperatures. The sowing is usually done in a 10-15 cm layer of cover soil.

Bed drainage is very important because an excess of water stops the fermentation process and the bed gets cold.

Horse manure produces a large amount of heat over a short period of time. Other materials, like leaves for instance, give lower temperatures but over a longer period. As a result, it is recommended to mix them when it is intended to extend the period of bed utilization.

The larger the bed the higher the temperature that can be obtained. But beds higher than 50-70 cm should only be used when a great amount of heating is necessary. For most situations, mainly when a tunnel or a greenhouse is being used, a 30-50 cm bed will suffice.

CHAPTER 4

ENVIRONMENTAL CONTROL

4.1 TEMPERATURE

Temperature directly affects the plant functions of photosynthesis, respiration, cell-wall permeability, absorption of water and nutrients, transpiration, enzyme activities, etc.

In practice, no important biological reactions can be expected from plants grown in greenhouses below 0°C nor beyond 50°C. The lower limit corresponds to the freezing-point of water and the upper one to the denaturation of proteins. The optimum temperature varies with species but nearly always falls within the 10 to 25°C bracket. Even though plants tolerate lower temperatures over short periods of time, this is to be seen as a tolerance rather than as a desirable condition.

As far as **"low temperatures"** are concerned, it must be kept in mind that a **threshold**, more elevated than the freezing point of water, determines for each species and even for each cultivar the temperature level below which the plant stops growing normally (either qualitatively or quantitatively). There is no common agreement among authors on how to determine the threshold of the different plants cultivated, but this is not the time for controversial discussions. For strawberries, the generally agreed threshold is about 7°C and for tomatoes it averages 12°C. But these figures are a mere indication.

Provided sufficient light is available (cf. §4.2), temperature is the most influential factor on the rate of growth and on the development of plants. Some experimental data show that the rate of plant growth increases with the rise of temperature until a desired level (= optimum).

4.1.1 HEATING OF THE GREENHOUSE

In winter, the climatic conditions in most parts of the Mediterranean region practically excludes open air cultivation of heat requiring crops (for example, tomato). This has induced growers to turn to greenhouses and shelters.

However, these allow "counter-season" cultivation (i.e. very early or very late out-of-season cultivation) only at the cost of real efforts made either to cut down heat losses - mainly at night (air tightness, double glazing, thermal screens) - or to provide energy artificially (traditional heating or the use of non-conventional energy : solar energy, geothermy, .).

In both cases, the grower faces the problem of profitability : **what is the limit beyond which investments** in special materials, in screens, or in solar or fossil energy heating **do not return a profit ?**

Energy supplied artificially is obviously to be regarded as an extra to those techniques which favour the saving of "natural" heat (cf. § 3.1.3 : Covering Materials and § 4.1.2 : Shading and Thermal Screens).

Mediterranean growers must therefore bear in mind that they may have to improve temperature conditions in their greenhouses if they wish to derive maximum profit from their investments. Most heating systems devised for glass-covered houses theoretically suit plastic-covered ones. However, there exists a wide range of relatively less sophisticated, low-cost systems which give positive results in the Mediterranean region.

Consequently, if the outside temperature falls below the inside temperature required by the crops, the greenhouse must be heated. To assess the capacity of the heating system, the heat requirement of the greenhouses has to be calculated. One can determine this heat requirement with the help of the overall heat consumption coefficient K' :

$$Q = A_H \ K' \ (t_i - t_a) \quad (W) \qquad 4.1.1.-(1)$$

The specific heat requirement per square metre of greenhouse floor area becomes :

$$q = \frac{A_H}{A_G} . \ K' \ (t_i - t_a) \quad (W/m^2) \qquad 4.1.1.-(2)$$

In these equations

K' (W/m²K) means the overall heat consumption coefficient

A_H (m²) the surface area of the greenhouse

A_G (m²) the floor area of the greenhouse

t_i (°C) the required inside temperature

t_a (°C) the average outside temperature

The heat consumption coefficient K' depends on the roofing material of the greenhouse, the air-tightness of the greenhouse, the heating system, the irrigation system, the wind velocity, the cloud-cover and the precipitation.

For plastic-film greenhouses one can use the following values according to the air-tightness for an average wind velocity of 4 m/s :

single film K' = 6 to 7,8 (W/m²K)
double film K' = 4,2 to 5,5 (W/m²K)

For the average minimum outside temperature one has to use values which are fixed as standards in the different countries. In Hanover, West Germany, t_a is -14°C. In many Mediterranean regions the average minimum temperature will have a value of about 0°C.

Example : heat requirement of a single film greenhouse with an inside temperature of 12°C :

$t_a = -14°C$ $q = 1,5 \times 7\ (12-(-14) = 273\ W/m^2$
$t_a = 0°C$ $q = 1,5 \times 7\ (12 - 0) = 126\ W/m^2$

4.1.1.1 Traditional heating systems

Undoubtedly, artificial heating by traditional means in the Mediterranean region is advisable only in those areas submitted to particularly cold winter weather or where horticultural enterprises are investing extensively.

As an example, and just to illustrate the problem and give an idea of the investments required (heating equipment being excluded), one may refer to Greek estimates which have concluded that to maintain 13°C in a polyethylene greenhouse all the year round, 12 l. of fuel are needed per m² of greenhouse in Ierapetra (Crete), 18 l. in Kalamala (southern Peloponese) and 24 l. in Thessaloniki (northern Greece).

Research has shown that even small differences in temperature around the plants grown in the same structure have a marked effect on yield and quality. To be able to obtain the maximum output from a greenhouse, Mediterranean horticulturists must consider the possibility to heat their shelters artificially during some periods of the year.

The heating systems commonly devised for glasshouses seldom used in plastic-covered houses because the structures of the latter are too light to support the heavy steel heating pipes. Furthermore, such systems would represent an excessive percentage of the total price of the construction. However, a wide range of lower cost equipment is offered to growers who wish to heat whilst remaining within reasonable investment limits.

"Anti-frost heating system" : there exist many types of heaters (using coal, wood, oil, natural gas and several organic materials as fuel) that can give satisfaction to achieve a temporary anti-frost heating. But they do not maintain a uniform temperature throughout the greenhouse and, if used in a "confined atmosphere" (i.e. without a chimney to remove the burnt gasses), they can damage the plants. For short-term use, these heaters are very useful for placing in plastic greenhouses owing to their low purchase price and the local availability of the various types of fuel.

High-speed hot water systems : in this system, which is readily adaptable and suitable for winter as well as for year-round production, hot water (60-80°C) is made to circulate in steel pipes 1 or 1.5 inches in diameter. An estimated 45% of the energy released is radiative. About 25% of it reaches the ground, the rest is directed upwards or towards the side of the house and may be lost quickly if the plastic film of the cover is too transparent to long infrared radiation. However, the system is expensive to install, causes losses of radiant heat and can sometimes cause a rise in relative humidity in the vicinity of the plants due to the absence or reduction of air movement. Some growers are now trying to use a new system whereby warm water flows in plastic pipes (3/4 - 1" diameter) between the plant rows. The temperature of the water at the entrance of the greenhouse is 50°C and at the exit, 45°C; per linear metre of a black PE tube 25 mm in diameter, 60 kcal are liberated.

Forced warm-air system. In recent years direct hot-air heaters have come into use as a means of avoiding the high installation charges of a boiler and a piped heating system, particularly in the smaller enterprises. The air is heated by direct exchange from the products of combustion and is distributed from the heater into the greenhouse via ducts (Figs. 62 and 63). This system produces vertical and horizontal temperature gradients; the vertical gradient ranges about 2 to 3°C per metre vertically, thus the temperature in the roof can be 5-10°C above that nearer the plants.

In Figs. 62 and 63, the plastic pipes run along the ground. But, depending on the cultivated crop, it can be better to place the air pipes above the plants, i.e., 1,75 - 2 m high.

The difference in temperature between the space around the heater and the end of the heated zone is less for air distributed through perforated PE ducts than where only a fan (without tubes) is used. Furthermore, the diameter of the perforations can be increased (and the spacing of these perforations must be decreased) in proportion to the distance from the boiler or from the main duct.

The plastic ducts are light, flexible, easy to install and can be fixed in the position best suited to the crop. At the end of the season they can be rolled up and stored. To obtain high efficiency and at the same time soil warming, the ducts should be on the soil with the holes turned downwards. Care must be taken not to expose the plants to the hot dry air discharged from the heating system. Mixing the hot air with the existing greenhouse air before it reaches the plant avoids any danger.

This system competes with the conventional pipe-heating system and is satisfactory for temporary heating or to raise the inside temperature some degrees above the outside one. Major temperature rises assume a considerable air movement with unfavourable side effects (further evaporation and difficulty in controlling carbon dioxide). Whatever the situation, the air velocity should remain below 5 m/sec.

This economical system operates on any type of fuel (coal, fuel oil, natural gas) and is adaptable to large greenhouses (central heater with local heat exchangers) as well as to small ones (one individual heater).

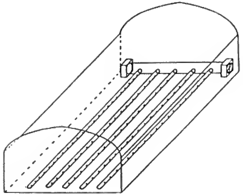

Fig. 62: Air-heating system with water-air exchanger and air distribution through perforated plastic-film tubes (*)

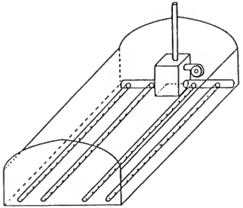

Fig. 63: Oil or gas-fired air heater with air distribution through perforated plastic-film tubes (*)

(*) von ZABELTITZ Ch.: "Gewächshaüser" - Ulmer Verlag, Stuttgart.
1e Auflage, 1978 - 2e auflage, 1986.

4.1.1.2 "Non-conventional" systems using solar energy

One of the most promising sources of energy, which is renewable, inexpensive and readily obtainable, is solar energy. Since a greenhouse is itself a huge solar collector the scientists are anxious to find out ways of using the extra heat dissipated through ventilation. All greenhouses are solar to some extent.

An effective greenhouse solar heating system requires three main components : a **collector**, a **storage system** and a **distribution system**.

The collector converts solar radiation into usable energy and heats up air or water. There are two major classifications of external solar collectors: concentrating collectors and flat plate collectors. Concentrating collectors are very expensive because they need a perfect vertical and horizontal mobility to follow the solar movement. In flat plate collectors, the solar radiation is absorbed by a dark surface protected by sheets of glass or plastic and the solar energy is converted into heat. (As traditional flat collectors are still too expensive to heat plastic greenhouses, the research has been directed towards the design of low cost plastic collectors).

Heating a greenhouse by means of simple external solar collectors is not free from disadvantages. Indeed:

- the system is difficult to integrate into an existing greenhouse
- labour and materials represent a considerable financial burden;
- collectors and greenhouses may compete with each other for solar radiation.

Studies are being conducted in various institutes to use the greenhouse itself as a solar collector, which obviously saves the cost of adding collectors. A greenhouse collector has several advantages over an external one. Indeed, the construction cost is more limited, no additional land is required and the transfer of heat from the collector to the greenhouse or to the storage suffers fewer losses.

So far, no economical method for storing the heat from low temperature air or water for subsequent use at night has been devised.

Solid materials (rock, limestone, tuff) can be useful for long- period storage, but for short periods (day-to-day), water is much more suitable and the storage volume is only 1/4.

Some phase-changing salts ($CaCl_2$, $Na_2Cr_2O_7$, etc.) can be used; they reduce the storage capacity required, but they remain too expensive.

If the greenhouse is provided with benches, the rock storage system may be located underneath (Fig. 64). The storing of the collected heat in rockbeds or water reservoirs inside or outside the greenhouse is costly because of the insulation needed. Besides, the distribution of heat is quite expensive since water pumps, fans and control equipment are to be operated.

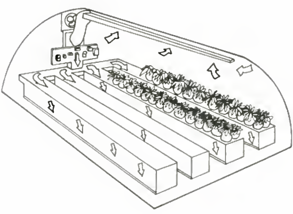

Fig. 64: Rock storage system in benches

Several research workers are investigating ways to use solar ponds for economical heating of greenhouses (Fig. 65). Indeed, with the addition of salt in order to increase the heat capacity of water, they offer the valuable advantage of collecting and storing the heat energy in summer as well as in winter. After receiving radiation for a whole summer, the water in the bottom half of the pond can be expected to reach a temperature approaching boiling-point. Unfortunately, prohibitive prices and the diffusion of salt from bottom to top (from the zone of higher concentration to that of lower one) are stumbling-blocks in the Mediterranean region. This sytem remains an experimental one.

Among the numerous solar systems developed so far in the various Research Centres all over the world, few can be classified as really cost-effective in the Mediterranean region. Many of them are not yet out of the experimental stage and efforts are being made to devise a system that will collect a maximum of energy for a minimum of expenditure and a maximum of efficiency. On the other hand, the greenhouses need a relatively large amount of energy for heating in comparison with what can be furnished by a solar system.

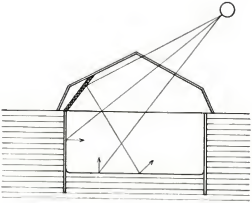

Fig. 65: A solar pond covered with a greenhouse

A very simple and promising solar system has been developed recently. The collector, the storage and distribution are one and the same. The water collects the solar energy while running down transparent polyethylene tubes ± 30 cm in diameter (100 cm in circumference) laid between the vegetable rows on a sheet of black polyethylene, itself lying on bubble film (Fig. 66).

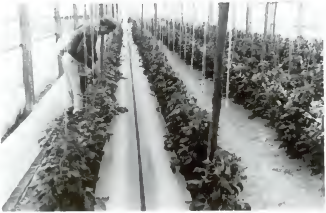

Fig. 66: Plastic tubes filled with water, used as collector, storage and distribution system for solar energy (Northern Greece)

These tubes are 200-250 microns thick and must cover at least 35% of the soil surface of the greenhouse. They contain ± 80 kg water/m² greenhouse. This system is already being used successfully in Greece, even in the northern part of the region, from the beginning of October until the end of May. Solar energy collected on one ha over this period is equivalent in this region to 180 000 l. of gasoil, i.e. 740 l. per day/ha. An increase of 4°C in the average minimum air temperature can be obtained in a single layer PE greenhouse (and of 6°C in a double wall PE greenhouse). This makes it possible, under a single PE wall, to keep tomatoes frost-free when the outside temperature is as low as -7°C (or -11°C under double wall). To install this solar system in 1 ha greenhouse, 2 500 kg of PE tubes are necessary as well as 300 kg of black PE sheet 30-40 microns thick, 3 500 m² of bubble film and 100 working days. The cost of materials and labour in Greece (1985) is approximately US$ 7 000/ha. Experiments have shown that under Greek conditions, this system can have a significant effect on the earliness, quality and yield of the most interesting vegetable crops.

In other regions (Tunisia) some experimental works are being conducted on flat polyducts of 150-micron black PE. Results show that even in the southern Mediterranean region, solar heating is not always sufficient in winter time. To allow easy cultural practices, covering should not exceed 50%, and therefore, additional outdoor captors or peak heating by air blower or other systems are needed to maintain the temperature of the water stored at a minimum level.

Note: Waters from complementary solar collectors, as well as from soft geothermy, industrial waters,... are generally characterized by relatively low temperatures (20-40°C). Therefore the exchange area of the radiators must be considerably increased without occupying too much space in the greenhouse. Hence the idea of **radiant mulch** (PVC or PE tubes) or **radiant "carpet"** (PP or elastomers): also the development of heating by ringed pipes (PP ones are laid out on the ground, while PE ones are in the soil).

4.1.1.3 Systems using other heat sources

A. Geothermal energy

A priori, one of the most interesting sources for heating greenhouses is geothermal energy. Hot water from natural springs and deep wells has attracted the attention of researchers who endeavour to harness it for practical purposes. Hot water from springs and boreholes is presently being used as an energy source in Mediterranean countries such as Bulgaria, France, Greece,etc. The main obstacles to the use of hot water to heat greenhouses are:

- the high salt content which leads to pipe clogging;
- the lack of suitable soil conditions to erect greenhouses where hot water has been discovered;
- the cost of systematic hydrogeological studies and deep well-drilling.

Recently, many Mediterranean countries have shown interest in using geothermal energy for heating greenhouses, and some interesting systems of heat distribution have been developed. One of the simplest and most effective systems has been developed in northern Greece.

This system distributes heat by circulating warm water in thin transparent polyethylene tubes (250µ) located on the ground between the rows of plants (Fig. 67). The diameter and the number of tubes depend on the water T°: if the water T° is above 50°C, the diameter of the tubes is 9.5-12.5 cm; for water T° of 30-50°C, the diameter must be 12.5-19 cm. The chemical composition of the tubes depends on the water T°: PE can only be used when water T° is under 60°C; above this temperature, PP is the only one to prove economic. In general, underground heating ducts seem less efficient (too high soil T°, insulating soil zone...).

Another simple way to distribute geothermal energy in greenhouses is to circulate the warm water through special black PE tubes 25 mm in diameter.

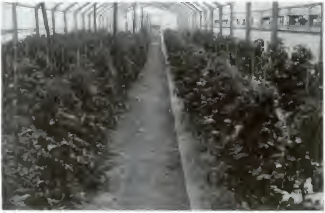

Fig. 67: Transparent PE tubes used to distribute geothermal energy in greenhouses

B. The utilization of waste heat

When horticultural fields are in the vicinity of large industrial units such as thermal power stations, the heat rejected by these could be regarded as a source of energy to heat greenhouses. However, the temperature of the water being rejected is often low (20-30°C) and recirculating it presents difficulties.

Various experiments have been carried out in industrialized countries which lead us to believe that this source of energy is not likely to be used easily in the Mediterranean region, except in some parts of southern Europe. The creation of new horticultural zones near thermal stations and the shift of farming population towards these new sites are not the major barrier preventing the 'low grade' heat of industrial units from being utilized ("ecological" fears to find nuclear residues in crops).

4.1.2 COOLING OF GREENHOUSES

One of the major problems encountered by greenhouse producers in the Mediterranean region as a whole is the control of excess heat. Even in winter time, on clear days, the temperature rises above the desired level inside the greenhouses and, during the summer period, temperatures above 50°C are not exceptional. From this point of view, classic greenhouses are unsuitable for cultivation during the period mid June-mid September in the southern Mediterranean region; in areas with an arid and/or semi-arid climate, this period extends from 15 May up to early October. In the northern Mediterranean region, it is possible - and desirable - to grow plants in greenhouses even in summer time.

Excessive temperatures cause damage to the morphology and to the various physiological processes of plants, such as flower shedding, leaf scorch, poor fruit quality, excessive transpiration, shortened life span of the plants, low net photosynthesis due to excessive respiration, etc.

On a clear summer day, the solar radiation level can reach as much as 1.5 cal/cm²/min. Even when the plant canopy is complete and can utilize 50% of the incoming radiation for evapotranspiration, the temperature rises above the desired levels. When the plant canopy is incomplete, evapotranspiration is reduced and the temperature rise is even greater. In such cases some form of cooling must be provided to ensure satisfactory crop production in the greenhouses.

The three weapons with which to fight excessive temperatures in a greenhouse are **ventilation, cooling by evaporation** and **shading.**

4.1.2.1 Ventilation

Ventilation of a greenhouse occurs both by design and by accident.

- **Accidental ventilation** is due to structural "defects" such as air gaps. Most plastic greenhouses are airtight and, as a result, infiltration is limited.

- There are two types of **"voluntary"** (by design) **ventilation:** forced ventilation and natural ventilation.

Forced ventilation

This is the most efficient way to ventilate a greenhouse. Thermostatically-controlled fans suck outside air into the house or inside air out of it; the second alternative looks more advantageous. Moreover, outside air must never be blown directly upon the plants.

The **capacity of the fan** should reach **1 m³** per minute for **each m³** of greenhouse volume so as to ensure a complete renewal (or at least three quarters of it) per minute (50 to 60 renewals/h).

Larger greenhouses should preferably be fitted with several two-speed fans with a view to increasing the flexibility and success of ventilation.

The rate of ventilation must be the result of a compromise between satisfactory growing conditions and reasonable financial investments on fans. No spectacular improvements are to be expected in temperature control nor in plant growth if air renewal exceeds one volume per minute. Air circulation is also of paramount importance. Without it, the plants near the ground are cold and damp, whilst heat is wasted at the top of the house.

Although the fan ventilation system is effective in reducing air temperature in greenhouses, the cost of equipment and the amount of electricity needed prohibit its extensive use in the Mediterranean region. Furthermore, it is not unusual for greenhouses to be located at places without electricity.

N.B.: The use of fans and air openings poses some problems concerning the design of the greenhouse and of achieving airtight openings in the building. These problems are examined thoroughly in § 3.1.2.

Natural ventilation

In the absence of forced ventilation, valuable results can reasonably be achieved with "natural" (or static) ventilation, provided that the openings are sufficient in number and in area. Efficient air movement must be allowed, and the openings must be fully airtight during cold periods. Large sections of the covering material must open easily (cf. § 3.1.2), and repeated handling must not cause premature wear.

In the case of plastic greenhouses, manually-operated side openings mounted on rollers provide adequate temperature control without entailing exaggerated costs (cf. § 3.1.1).

Greek researchers have mechanized the opening and closing operations of side ventilators in plastic-covered greenhouses : the system is operated by a thermostat-activated electric motor (Fig. 68).

Another system is being experimented with in which the opening of the side ventilators is achieved by a special metal tube filled with an expanding liquid.

However, as already said, no positive results are to be expected from natural side openings unless the greenhouse is under 20 m wide and the total opening surface represents at least 20% of the floor area of the greenhouse.

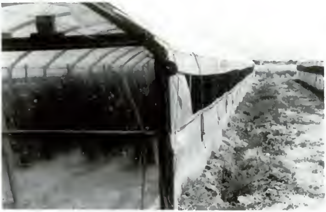

Fig. 68: Side ventilation operated by a thermostat-activated electric motor (Greek system).

4.1.2.2 Evaporative cooling (Fan and pad system)

Another more effective way of cooling greenhouses in areas where high temperatures are the rule during warm seasons is the **fan and pad system.** This system is based on the principle that, when water evaporates, heat is absorbed from the surroundings. This is achieved by drawing air through wet pads. The air cooled by evaporation passes the plants before being exhausted outwards.

The fan and pad cooling system is characterized by the following:

- electricity and relatively large amounts of water are required;
- success depends on a low level of outside air humidity;
- water is saved, even if an additional misting of the greenhouse seems necessary;
- it should be possible, if necessary, to use saline or brackish water without clogging the cooling pads;
- dry "dusty" regions require dust-tight greenhouses;
- the distribution of air must not result in high temperature gradients within the house;
- the water used must be kept cool in an underground storage tank;
- the system must prove efficient in high winds and be practically independent of the wind direction;
- the price of the installation is principally related to the cost of the fans in the region considered.

Basically, two systems are to be distinguished (Fig. 69):

- the negative pressure system;
- the positive pressure system.

The **negative pressure system** (a) consists of an evaporating surface on one side of the greenhouse and suction fans on the opposite side. This method creates temperature gradients between the air intake and the air outlet. There is uncontrolled air intake through leakages in the structure, and dust can also enter because of reduced pressure inside the house.

The **positive pressure system** (b) gives a more uniform temperature and allows no dust in. The fan blows the air through the pads and then through the greenhouse.

Air may also be distributed through perforated plastic tubes. The air exit is at the side walls (c).

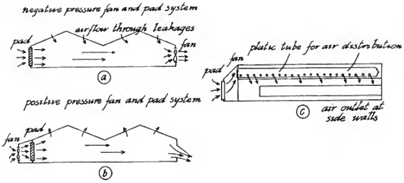
negative pressure fan and pad system
airflow through leakages
pad
fan
a
platic tube for air distribution
fan
pad
c
air outlet at side walls
positive pressure fan and pad system
pad
fan
b

Fig. 69: Fan and pad cooling systems.

The installation of a **fan and pad system** in the space between two greenhouses advantageously combines it with **free ventilation** (Fig. 70).

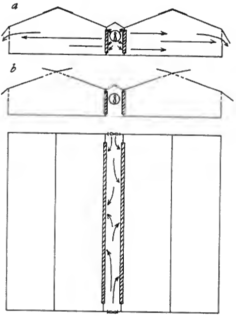

Fig. 70: Combination of positive fan and pad cooling with free ventilation.

The pads can be positioned vertically or horizontally (Fig. 71). The horizontal position is to be preferred since it slows down the clogging process. Passing more water through the pads than is theoretically required for evaporation further slows down clogging. As water evaporates, cooling takes place causing a corresponding increase in relative humidity.

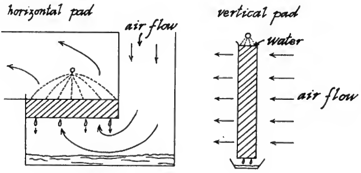

Fig. 71: Horizontal and vertical positions of pads.

When the outside relative humidity is high, the efficiency of this system is very low.

Useful recommendations

1. Greenhouses with evaporative cooling should be located so as to take advantage of prevailing wind direction. Wet pads should be located on the wall of the greenhouse facing the wind and the fans located on the lee side.

2. Between the pads and the fans there is a temperature gradient inside the greenhouse. To reduce the uneven temperature distribution it is recommended to:

   - seal all cracks and holes in the structure;
   - limit the maximum distance between fans and pads to 40 m;
   - increase the number of fans for more efficient air flow;
   - locate the pads at both ends of the greenhouse and the fans on the roof in the middle of the greenhouse if the latter is more than 40 m long;
   - install spray nozzles in the greenhouse for producing additional mist.

3. Near the pads the cold air can be detrimental to plants. Consequently, it can be profitable to deflect the cold air stream coming from the pads.

4. When using brackish water, horizontal pads are recommended because the water flowing downwards through the pads has a self-cleaning effect.

5. The water utilized in the system should be recirculated through a reservoir because colder water is better than warm water.

6. Water pressure must be maintained uniform to keep the pads adequately sprayed and thoroughly wet.

7. For maximum cooling the greenhouse should be shaded.

Figs. 72 and 73 show the rates of water evaporation and of air exchange through the pads in relation to the outside temperature at various levels of relative humidity. The inside temperature is set at 30°C. The values for water and air are related to one m² of greenhouse ground area. If the relative humidity is above 30%, large amounts of water and air are necessary.

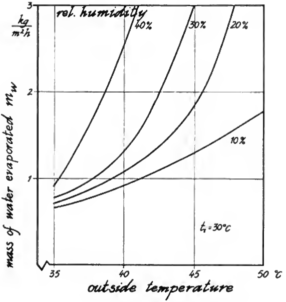

Fig. 72: Evaporation of water depending on outside T° and relative humidity. (R.H.)

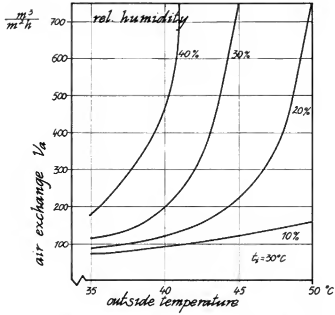

Fig. 73: Air exchange through the pads depending on outside T° and relative humidity (R.H.)

For instance, if R.H. is 20% and the outside T° is 45°C, the theoretical quantities needed per m² per hour are: 1.8 kg water and 210 m³ air.

The calculation of the power for the fans is similar to that for forced ventilation (§3.1.2).

The electric power for the fans is :

$$P = \frac{V_A \cdot p}{\eta} \quad (W.m^{-2}) \qquad 4\text{-}(3)$$

where V_A (m³/m².s) = ventilation rate (Fig. 73)

p (P_a = N/m²) = pressure loss through pad and greenhouse

η (-) = fan efficiency

The pressure loss through the pads is 20-50 Pascal (2-5 mm water).

Fan efficiency is about 0,7.

With the above mentioned example, if

$V_A = 210 \text{ m}^3/\text{m}^2.\text{hr} = 0{,}058 \text{ m}^3/\text{m}^2.\text{s}$

the power is

$$P = \frac{0{,}058 \ . \ 40}{0{,}7} \ (\text{W/m}^2) = 3{,}3 \text{ W/m}^2$$

The electric power is about 3,3 W per m² greenhouse floor area during the operation time. Per 9-hour day of operation time, the fan and the pad cooling system consumes 30 Wh/m².

Compared to simple forced ventilation, a pad cooling system consumes 65% more electricity (30 Wh/d/m² instead of 18 Wh/d/m²) but this is small in return for the improved efficiency of the cooling system.

As already mentioned before, the water flow has to be higher to prevent salt precipitation inside the pads. The insects that are sucked into the pads and the mineral deposits that build up on the pads restrict the air flow and, consequently, the efficiency of the system.

N.B.: The **fine mist system** and the **coarse mist one** are **two other evaporative cooling systems** that have found application in commercial horticulture thanks to their low cost.

Spray-nozzle misting decreases the inside air temperature mainly as a result of the evaporation of water. Spray-nozzles can possibly be combined with fan ventilation without pads.

It is interesting to note that every gramme of water that evaporates produces a quantity of "cold" corresponding to 600 frigories. The different parameters that have to be kept in mind when designing a cooling installation are:

- the total volume of the greenhouse;
- the number of air exchanges at 3mm static pressure (45-60);
- the surface of the wet pads and the number of fans (average distance between them : 7 m).

As an indication, the power of the motors which drive the fans is from 3 to 5 W/m² of covered surface. Due to the high cost of the installations, evaporative cooling systems in the Mediterranean countries are restricted to some flower production farms.

- **The main advantage of the fan and pad system** is its capacity to cool the air of the greenhouse at a reasonable cost. Furthermore, it increases the quantity of water in the greenhouse atmosphere without bringing humidity up to an excessive level. Plants consequently do not suffer from unduly low saturation deficits. Though an evaporative cooling system is more expensive than free or forced ventilation, it remains the only system that allows the production of plants in greenhouses in many arid regions (where temperature is quite high and moisture quite - or even too - low). It is less advisable for the northern part of the Mediterranean region.

- The authors are unaware of any inexpensive greenhouse cooling systems that can keep the **temperature inside the shelter below that outside**. The cost of refrigerated cooling is quite prohibitive.

In experiments carried out in Israel on a closed system greenhouse, a solution which absorbs the solar near infrared is circulated between the two surfaces of rigid double wall covering materials (PMMA). But this system does not reduce the inside temperature below the outside one.

4.1.2.3 Greenhouse shading

A. Shading screen

In some particular cases, the greenhouse cover is removed during the warmest months of the year and a shading screen is substituted, constituting the only protection offered to the plant (= "ombrières" in French, or "shading units"); it reduces wind effects quite considerably and cuts down to a certain extent the radiation reaching the plants.

Since the available light is reduced permanently and the protection from possible (night) cold is rather illusive, such a method seems restricted to:

- those regions where insolation is quite strong in summer and the night temperatures are not too low;
- the protection of some particular plants from radiation levels that they cannot tolerate due to their sensitivity (some varieties of ornamental plants) or at particular periods of their lifetime (when in the nursery).

Since these "shading units" are supposed to perform better than the techniques that use the natural shade from a vegetative canopy, they must satisfy a number of principles. They are expected:

- to provide a shading that can be interrupted when insolation is not excessive (in winter). This means that the shading covers must be designed so as to allow disassembling and that the shading nets are supposed to be removable;
- not to hinder mechanization or crop husbandry.

Two types of shades can be erected :

- large, fixed structures
- low, mobile tunnels.

The large fixed shading units are much the same as the "Parral" greenhouse except that they are lighter and taller and are covered with easily removable materials (home-made materials, but above all the special extruded polyethylene nets that slide along wires stretched over a frame).

The small, mobile shading units are made up of wires stretched some 30 cm above the ground and about 1 m apart. The PE film is being replaced by a non-rigid woven net that does not absorb water, is mold-resistant and does not harbour parasites.

The expenses entailed in removing the cover and laying the shading screen represent the major handicap of this system. When films and screens are intended to be used for several consecutive years, the shelters must be built to suit the requirements of the technique; moreover, besides storage problems, there are also risks of tearing.

On the other hand, only the mechanical qualities of the screen - and to a lesser extent - its ability to withstand winds without damage seems to have some significance, contrary to what happens in the case described below.

B. Shading

As a rule, shading supplements ventilation (and/or misting) when these techniques fail to keep the inside temperature within reasonable limits.

No description is given in this paper of the various attempts that are being made on interesting but unduly expensive techniques (for Mediterranean conditions).

a. **Spraying** the covering material **with a mixture of a lime-based product** and a wetting agent remains the most commonly used method in the Mediterranean region, but this system does not apply to all cases indistinctly. The application is often somewhat empirical, though radiometric measurements show that the proportions recommended for the products used in northern Europe reduce the incident energy by some 50%. This estimate is also applicable to the Mediterranean region, and the use of a fixing material would avoid washing away of the protection by rain.

b. **Some other products** - more or less sophisticated - have been or are being surveyed, e.g.

- a substance which is applied as a thin film over the covering material and which turns transparent when wet, i.e. in the rain;
- a shading material (developed in Greece) which becomes more transparent when wet and which reduces the air humidity of the greenhouse on dull days as a result of its hygroscopic components.

c. **Water spraying** by means of spray lines mounted at **the top of the greenhouse** may help to reduce the inside temperature. The very nature of the experiments carried out in the Mediterranean region and, as a consequence, the results of these are quite diversified. This explains the lack of unanimity among research workers and extension workers on this technique.
However, this technique requires costly equipment, particularly if water storage is necessary, and consumes large quantities of water (the same technique proves more successful in northern Europe where it is used to limit the inconvenience caused by cold weather in winter).

d. The use of **coloured water** has been discontinued in Europe as a result of the high costs and complexity of the equipment. The only remaining application is when the absorbed solar energy is used, after storage, to warm up the greenhouse (solar greenhouse).

e. In some cases, e.g. for the cultivation of valuable ornamental plants, growers use **shading screens** which - to facilitate operations and because they can act as thermal screens in cold weather - are unrolled inside the greenhouse instead of outside (as they should to respect thermal balance).

C. Some considerations on the shading of greenhouses (*)

It is taken for granted nowadays that when there is a high level of insolation, an untimely rise of the temperature of the plants or of the ambient air is more damaging to the plants than excessive visible light. Such an excess of "heat" is often accompanied by water supply problems and the plants fail to maintain their temperature within reasonable limits.

Therefore, **an ideal shading screen must:**

a. **be selective:** it is not sufficient to cut down "part of the solar radiation"; this part must be the near (thermal) infrared one and not the visible one as the latter is indispensable to photosynthesis. Even in the Mediterranean region, it is unthinkable for shading to be synonymous with lack of light since such a lack is all the more harmful to plant growth when the temperature is high.

N.B.: Selectivity is mentioned first as it is felt to be the prime quality of a shading screen. Unfortunately, it has to be admitted that so far (1985), no such type of screen has yet been produced economically despite the serious studies conducted in this field.

b. **not be coloured:** this "quality" derives from the previous one, since any coloured material cuts down a more important fraction of the visible spectrum than its non-coloured counterpart. This fraction corresponds to its complementary colour (e.g. an orange or red screen absorbs a greater quantity of blue, which creates an unbalance in the spectrum of available light). Furthermore, this additional loss of light (visible) occurs normally by absorption, which doubles the harmful effect of the coloured screen on the growth of plants in that it increases the temperature of the greenhouse;

c. **reflect rather than absorb** the part of the solar radiation that it cuts down. A screen that reflects radiation (without absorbing it) does not heat up and consequently does not increase the temperature of the structure it protects as much as an "absorbing" screen does. So, when a screen reflects the solar infrared, the latter may leave the greenhouse in the way it entered, i.e., by radiation, without causing the "greenhouse effect";

d. **have an adjustable intensity:** automatically-operated shading screens have the merit of suppressing when necessary the surplus incident energy, but do not at the same time optimalize the light balance of the greenhouse in favour of the plants. As soon as a (slight) excess of heat occurs, a screen is unrolled that causes a major reduction in available light, whereas the degree of shading should preferably be related to the level of radiation;

(*) NISEN A. (1981). "Ombrage et isolation nocturne des serres" - l'Horticulture française - sept-oct. 1981 - Paris.
NISEN A. et COUTISSE S. (1981). "Modern Conception of Greenhouse Shading" Plasticulture N°49 - Paris.

e. **be removable**: even in the Mediterranean region, a shading screen that cuts down an important part of the solar radiation (60 to 80%) cannot be left unrolled all day long and - a fortiori - for months on end. Furthermore, the variations in radiation throughout the day are such that, in order not to compromise photosynthesis, it is imperative to fit the structure with shading equipment that can be unrolled only when the solar energy becomes excessive;

f. **be located outside the greenhouse**: this principle is mainly true when the screen absorbs the solar radiation (to ensure a positive daytime thermal balance). But shading screens are generally placed inside because they are also used as thermal screens at night, for economic reasons.

g. **not prevent ventilation** even when unrolled. Obviously, when the ventilation openings are located along the ridge of the roof, a shading screen unrolled inside considerably hinders air renewal.

h. **be of reasonable cost**: this quality is of course of prime importance but it is unfortunately seldom met. However, once the use of a well designed shading screen contributes to increased crop yields, its price is not so important; yet it is not easy to advise the Mediterranean grower to enter into major financial commitments.

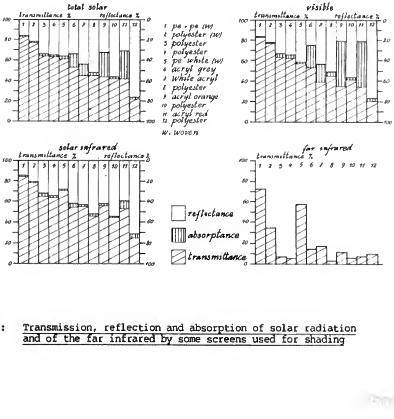

Fig. 74: Transmission, reflection and absorption of solar radiation and of the far infrared by some screens used for shading

The chemical constitution of the screens presently marketed does not need a detailed description. As Fig. 74 shows, some of them are coloured, others are not; the basic constituents are PE, EVA, polyesters, acrylic or a mixture of such resins; they may be woven (W) or not.

It is at once apparent that none of them can be held as a shading of real worth : more often than not they absorb rather than reflect the solar radiation, they are coloured and non selective, their intensity is not adjustable and automatic rolling and unrolling is difficult to achieve in the Mediterranean region.

A newer type of screen has just been produced which, though imperfect, is already an important step forward compared with the above screens : they are made of a transparent film covered with reflecting strips (based on aluminium, or similar products : chrome, for example) so as to create shadings of variable intensity.

Unfortunately, attention must be drawn to the following defects that detract from the shading screens currently available:

- the percentage of shading mentioned in the prospectuses distributed by commercial firms seldom corresponds to that actually determined in laboratories;
- all the materials are less transparent to diffuse radiation (clear sky and, above all, cloudy sky) than to direct solar radiation;
- the intensity of colouration of a screen has no direct bearing upon its shading power : one should be wary of assessing the quality and intensity of colouration by eye.

4.1.3 HEAT CONSERVATION

The majority of greenhouses in the Mediterranean area are not heated (apart from shelters used for the cultivation of ornamental crops). It is, therefore, vitally important to maintain heat inside the unheated greenhouses both as long and as efficiently as possible.

- When the greenhouse is fitted with a self-acting temperature regulator and has an artificial heating system, the temperatures "at the thermostat" may be lowered; this means that the required day and night temperatures may be lowered to the economic limit, i.e. the point where savings on heating costs no longer balance the losses caused by decreased output or earliness of production. Unfortunately, the precise requirements of the cultivars grown are not fully known. Few growers are attracted by such adventures; they do not want to run the risk of bitter disappointment. However, this together with the choice of less heat-demanding cultivars theoretically looks the most elegant way to save energy. (One need not be reminded that cultivars behave quite differently from each other, and that greater efforts should be made to focus on low requirement varieties, particularly when the greenhouse has no heating system).

- When the greenhouse cannot be fitted with artificial heating, the only way to avoid dramatic falls in temperature at night is to ensure the maximum conservation of solar heat received during the day (limitation of losses through the walls and the interstices : the bonding of sidewalls to gables is often substandard and needs careful checking). There exist various ways at present but, even though they may have some degree of efficiency, none of them looks really profitable with the exception of the double-wall and thermal screen.

4.1.3.1 Inflated or uninflated plastic double wall

In the northern part of the Mediterranean region, although heat losses are reduced by 30 to 40% when the material utilized for one of the two walls is not permeable to the far infrared, the minimum night temperature can fall below the growth threshold of the crop. Furthermore, yields may be observed to decrease because the second plastic screen reduces the available light.

There are a number of lining systems used in the Mediterranean region, and each of them is made to fit a particular type of greenhouse. The principle consists in stretching - by some means or other - a second plastic film a few cm apart from the cover of the greenhouse. This film can be 50 to 100 microns thick. Lining with a modified or "charged" PE film obviously improves the thermal balance.

The most sophisticated way, but which proves highly efficient, consists in inflating the two films with air. The air space created between the two PE sheets constitutes an effective barrier to heat flow, reaching an optimum value when the air space is 2-10 cm. Energy saving can reach in this case 40-45% when the greenhouse is heated, and the minimum temperature observed during the night may be 2-3°C higher than in the case of a single PE cover.

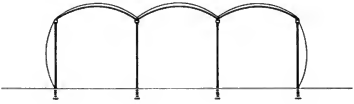

Fig. 75: Polyethylene double wall with air under pressure ("inflated")

4.1.3.2 Thermal screen unrolled at night

This, in a way, is an efficient though costly improvement of the previous method : the second film, which is made of better insulating material, is unrolled at night. Unfortunately, really efficient screens are rare if they are also used as shading.

The major items of cost regarding screens are the mechanical system, the sewing of materials and the installation. Some greenhouses seem to be more easily fitted with a screen than others.

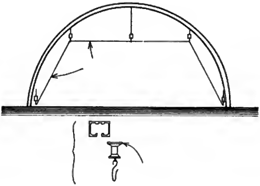

Fig. 76: Laying and fastening of a thermal screen in an arched greenhouse (ROBERTS, USA)

The efficiency of a screen - i.e. the increase in minimum temperature it affords during night-time in a cold greenhouse - mainly depends on the quality of the screen, the tightness of the system, the quantity of insolation gathered before closing, the opening and closing times of the screen, etc. Some of the problems linked to the utilization of a screen are the high cost, the shading of plants by the screen when rolled with subsequent reduction in production, the accumulation of water condensation on the screen, the increase in humidity (*) within the greenhouse because of reduced ventilation, the sudden drop in temperature in the shelter when the screen is rolled in the morning, etc.

N.B.: (*) A special plastic film ("anti-drop" and very clear) which can be used night and day as a thermal screen has just been developed : the reduction of light in the shelter is very low and the efficiency for the Mediterranean area is appreciable.

Qualities of an "ideal" thermal screen

To be an "ideal" insulating material, a screen should combine all the following qualities; it ought to :

a. **reflect rather than absorb the far infrared** of the greenhouse : a screen that reflects rather than absorbs the far IR (emitted by the plants, the soil, the artificial heating,...) does not heat up and, therefore, transmits a smaller part of that heat outwards, and thus considerably improves its effectiveness;

b. **be removable** : even if a doubling material for greenhouses is supposed to be transparent, it always causes some additional loss of light, which often exceeds the tolerance threshold (cf. § 4.2).

With greater reason, a somewhat opaque material must be designed so that it can be removed as soon as the available light is no longer in excess (morning, evening, cloudy sky,...);

c. **be as insulating as possible** in itself, i.e. have a very low "k" and also be laid with great care so as to make a cover without breaks of continuity (cracks), which are responsible for very active "chimneys";

d. **be cheap** : the purchase price of "non woven" thermal screens is generally lower than that of woven ones, but the expected duration of life is a factor that counts in the estimate of the real cost of each individual screen.

A survey of the properties of the screens used as thermal screens and of the systems available commercially shows that very few of them satisfactorily meet the above requirements.

The user is therefore advised :

- to choose the screen with care;
- to assemble his system perfectly, particularly as far as tightness is concerned.

Note: It has been shown that:

- on the one hand, very few screens make up a perfect shading, and
- on the other hand, equally few can be considered as good thermal screens.

4.1.3.3 Use of shading as thermal screen

From the moment a covering film is also supposed to be used as shading, or when a shading screen is given the role of thermal screen, the efficiency remains well below the expectations and more often than not it results in more harm than good.

To be used as thermal screen, a shading material must :

- be inexpensive and have a sufficient durability;
- be selective in the reflection (and not in the absorption) of solar radiation;
- reflect enough of the long IR by its lower face;
- reflect efficiently the solar IR by its upper face;
- have a low "k" (thermal transmission);
- have sufficient transparency in the visible ...

Let there be no illusion, **among the materials currently marketed none can be claimed to display all these qualities at a sufficient level.** It is up to the user to discover the material that bears the closest resemblance to - not to say that deviates the least from - that which could be held as ideal.

Experiments and tests conducted in different places of the Mediterranean region have shown that thermal screens can be used economically **only** in heated greenhouses. In non-heated PE shelters, thermal screens show a very small effect on the increase of air temperatures (2-3°C); higher night temperature gradient between inside and outside needs double glazing (i.e. double PE layer, double skin...).

4.1.3.4 Other techniques

The three techniques described above, together with skilled management of the greenhouse (right time to close ventilators in the afternoon in order to conserve a maximum of heat for the cold hours of the night...) still prove insufficient in some parts of the Mediterranean region and at some periods of the year. Therefore, they should be supplemented by other techniques which, more often than not, have an indirect impact on heat preservation despite the important role they play in energy saving. The efficiency of such methods is difficult to estimate, and the grower seems the only person able to assess their profitability with regard to the particular conditions of his enterprise:

- isolating all the opaque parts of the greenhouse (and in particular the gutters) which can create thermal bridges;
- lining restricted to the north wall by means of a bubble PE film or of one with a low "k" coefficient;
- protection of the greenhouse from cold winds by means of windbreaks casting no shade on crops; (§ 3.4.1);
- whenever possible, insulation of the bottom part of the greenhouse, and, in the colder regions, of the foundations;
- spraying of water over the roof during the coldest periods (cf. Fig. 77);
- spraying of water over the thermal screen (inside the shelter), this water being recollected in a gutter placed at the lowest part of the oblique portion of the screen;
- maintaining sufficient humidity within the greenhouse (though it must never be excessive).

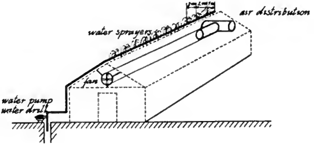

Fig. 77: Spraying of water (at night) over the roof of a greenhouse

N.B.: The techniques developed in highly industrialized countries but which are obviously unprofitable in the Mediterranean region at present have not been listed here (insulation of double walls by means of expanded polystyrene pellets or by means of liquid foam, use of inflated polyethylene sheath to line the roof at night ...).

Other possibilities exist for creating a better protection of the plants grown under shelter : e.g. the building of low tunnels (permanent or temporary) inside the greenhouse.

Some references:

1. GRAFIADELLIS M. [1976] "The control of air temperature in plastic greenhouses". First Agricul. Res. Symposium Bi: 302-309 (in Greek).
2. GRAFIADELLIS M. [1982] "The construction of an external plastic solar collector for heating greenhouses". First national congress on the use of renewable sources of energy. Volume A: 185-196. Thessaloniki, Greece (in Greek).
3. GRAFIADELLIS M. [1982] "The construction of a collector-distributor of energy in greenhouses". First national congress on the use of renewable sources of energy, Volume A: 177-184. Thessaloniki, Greece (in Greek).
4. GRAFIADELLIS M. et al [1985] "A study of different greenhouse heating systems". Research Report I: 1-40 of Agricultural Research Center of Northern Greece, Thessaloniki, Greece.
5. GRAFIADELLIS M. [1985] "Development of two systems for heating greenhouses with geothermal energy". Research Report I: 41-57 of Agricultural Research Center of Northern Greece, Thessaloniki, Greece.
6. GRAFIADELLIS M. [1985] "Development of a passive solar system for heating greenhouses". Proceedings of the second national congress on renewal sources of energy HEG 9-16. Thessaloniki, Greece.

4.2 LIGHT

Nobody doubts the important role played by light on crops : greenhouses must collect a maximum of solar radiation all day long in winter, and every morning and every evening all the year round in order to get a favourable thermal balance from the short IR and allow active photosynthesis through the "visible" (provided no factor involved in the process falls down to a minimum).

The ways in which greenhouses located in medium latitudes (higher than 50°) may be designed to collect maximum light have already been debated at length. **The pitch of the roof**, or rather the shape of it (more or less arched) as well as **the orientation of the structure** are the key features.

In **northern Europe**, the higher the angle of pitch, the greater the quantity of insolation the roof collects; moreover, E-W orientation increases the quantity of energy collected in winter.

In the **Mediterranean region**, i.e. at latitudes ranging from 30° (Cairo) to 45° (Avignon), the problem does not seem so acute as it does in Belgium or in Holland (50-52° latitude).

The **global light** (sun + sky) **collected by a horizontal surface** on **15 December** (winter solstice) when the sky is clear and nebulosity is average leads us to observe that :

- the potential insolation at the latitude of Nice is exactly twice that recorded in Brussels or in the Dutch Westland;
- in Algiers, Almeria and Malaga it is more than three times as high;
- in Agadir and Cairo it is more than four times as high.

Table 13: Daily global lighting (sun + sky) collected under clear sky on 15 December in relation to latitude (W.h./m²/d) (medium nebulosity - horizontal surface) (from J. NIJSKENS)

Latitude	52°	43.5°	42°	37°	35.5°	30°	23°
	Brussels Naaldwijk	Avignon Nice	Rome Skopje	Algiers Tunis Almeria Malaga	Crete	Cairo Kuwait	Mecca
Sun	419	1 166	1 331	1 954	2 130	2 875	4 265
Sky (clear)	399	470	492	564	587	699	859
TOTAL	818	1 636	1 823	2 518	2 717	3 574	5 124

Figure 78 shows the same potential lighting for medium turbidity (turbidity coefficient : 3.20) on 15 December and gives an idea of the insolation in some towns and areas not listed in the table.

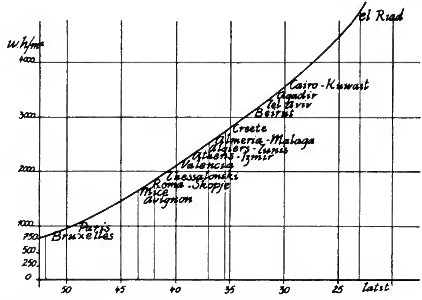

Fig. 78: Daily global lighting (sun + sky) collected under clear sky on 15 December varying with latitudes (medium turbidity - horizontal surface)

The ratio of minimum potential lighting (15 December) in the Mediterranean region ranges from 1 to 2.2 : 1 636 W.h.m^{-2}/day in Avignon and Nice and 3 574 W.h.m^{-2}.d^{-1} in Cairo so long as the sky is clear. **The actual variations in insolation are obviously more important** since some regions are more humid than others (rainfall : 1 500 to 1 800 mm in Tanger, 300 to 500 in Almeria and Malaga). Such local variations in actual lighting must of course be taken into account.

The following points can be taken for granted without further estimate (see table and figures above) or observation (§ 2.1 "climate").

1. Even if there is a one-to-two ratio in winter lighting in the Mediterranean region, the average values there are 2 to 4 times as high as in those parts of Europe in which greenhouses are concentrated (50-52° latitude North).

2. The pitch of greenhouse roofs or the arched form of the shelters helps to improve the light balance of the structures in the Mediterranean region, but the light balance due to the form of the shelter roof is not a limiting factor as it is in northern Europe.

3. Other climatic factors (listed beyond) become more important than light as demonstrated by the data listed in the above table and figures and by the variations of actual insolation.

The problem needs relativizing, and mere extrapolation to the Mediterranean region of the conclusions from surveys carried out 1 000 or 2 000 km further north is to be ruled out.

In order to understand the importance of the problem of light losses due to unsuitable pitch or orientation, studies by D. KLAPWIJK (*) may be referred to. He claims that at 52° latitude North and in the insolation conditions prevailing in Holland, light has an appreciable influence on the development of tomatoes in autumn and in winter - the weaker the light, the more important the influence - but from 21 March to 31 September there is no such influence. "It must be pointed out that the growth rate of tomatoes decreases (in the Netherlands) linearly from the moment they receive a "large amount" of light (21 March-21 September) up to the time when they receive little of it (21 December)". Between 21 March - 21 September, the growth rate remains constant though the available insolation undergoes great changes. The insolation received in Holland from 21 March seems to D. KLAPWIJK to be the threshold from which the influence of lighting variations plays but a secondary role.

Now, one must point out that potential lighting under a clear sky on 15 March (horizontal surface, medium turbidity) in Holland is 3 694 $W.h.m^{-2}d^{-1}$, i.e. the same as that recorded (cf. Fig. and Table) in the southern part of the Mediterranean region at winter solstice. Other estimates can show that even if this value is not reached in the northern part of the Mediterranean region, the lack of light is - in the most favourable conditions - much lower (two times) than it is in Holland and extends over a much shorter period.

In those parts of the Mediterranean region located between 45 to 30° latitude North, the importance of light to crops grown in greenhouses seems to decrease even in winter and there appears to be a link between this and the decrease in latitude. Light becomes secondary to other factors such as :

- **The degree of dirtiness of the plastic covers**; the way they fix dust. Indeed, this can cut light penetration through the covering material by 30 to 50% and endanger photosynthesis seriously; the very nature of the plastics used and their electrostatic power are more fundamental than the shape and orientation of the structure;

- **The way heat losses are controlled**, especially through plastic double film: to provide a greenhouse with a permanent second film or to use a thermal screen during the early hours of the day amounts to doubling the light losses; this means reducing the available insolation by at least 20 to 30%. Such a reduction appears more important than variations in available light due to unfavourable shape or orientation of the greenhouse.

- **The framework material**: at the beginning of plasticulture (1955) - and even nowadays in those poorer regions which have recently adopted this technique - the grower himself made the framework of his greenhouse, using various materials, some of them second-hand. Wood obviously casts more shade than metal does, and this can become a drawback, especially when the framework is made up of boards placed on edge.

- trees or bushes used as **windbreaks** give shade to the greenhouses they are supposed to protect.

(*) D. KLAPWIJK (1982) : "Plantenfysiologie in de glas tuinbouw". Informatie reeks n° 78 Naaldwijk en Aalsmeer (NL).

The structure may be given a **shape and** an orientation to resist **predominating wind**. There is no unanimity on this point. Some research workers claim that greenhouses should be built parallel to the wind while others prefer them to be perpendicular to it. This opposition must have originated in the difficulties observed at the openings of the structure (doors and ventilation openings). Greenhouse manufacturers try to design structures which offer the least possible resistance to wind : gentle slope of roof pitches, reasonable arching, openings parallel to predominating wind (when it exists...). Each case needs individual consideration.

Furthermore, it is worth recalling that the **transmission factor** of **greenhouse covering materials** (§ 3.1.3.1) as well as that of **shading** or **thermal screen materials** (§ 4.1.2) is lower for **diffused radiation** (sky) than for direct radiation (sun); the difference can reach 7-10% according to the material. Similarly, the values recorded under a cloudy sky are lower than those under a clear sky in roughly the same ratio. As a result, the transmission factor of some materials in **cloudy weather** may be limited to 80-90% of the value found in sunny weather.

Finally, as already said before, in the Mediterranean region it is the orientation **of the rows** rather than the shape and orientation of the greenhouse that is to be checked to provide plants with maximum light.

In conclusion, it may be said that, due to the importance of solar radiation in the Mediterranean region, the pitch of the roof, the shape and the orientation of the greenhouse play a lesser role than other techniques that cause a greater loss of available light.

4.3 HUMIDITY

Humidity is one of the environmental factors which must be in proper balance for satisfactory greenhouse cultivation. The influence of humidity in the complex greenhouse environment has not been investigated as thoroughly as other factors, perhaps because of the difficulties of accurate measurement and control.

The air in the greenhouse is enriched with water vapour by evaporation from the soil and by transpiration of the plants.

At night, evapotranspiration is relatively unimportant because transpiration is restricted due to the stomate closure and evaporation of soil moisture is insignificant due to the thermal evaporation potentials which exist; but as the temperature decreases in the shelter and since relative humidity (R.H) varies inversely with T° - for a constant absolute water content of the air - the R.H. increases and can reach very high values.

During the day, when heating by solar radiation occurs, the absolute humidity of the inside air rises with the sun, because the stomate opening increases transpiration. At the same time, the relative humidity can decrease (with increase of T°) and in some cases can go down to low values, especially when ventilation is applied. Plants definitely influence air humidity through evaporation : a tomato crop can evaporate, in the "best" conditions, up to 15 g of water/m^2 of greenhouse area/min. ($\simeq$1 l/m^2/h!).

When discussing humidity in greenhouses, the following points are worth considering :

1. Definitions and dependency of humidity;
2. Influence of humidity on the greenhouse climate;
3. Control of humidity.

Plants have to transpire water to transport nutrients, to cool and to regulate growth. The transpiration depends on the saturation deficit between the stomates and the air. The following can be said :

- Too high and too low saturation deficits have an unfavourable influence on plant physiology and plant growth :
  - When the air humidity is too high, gas exchange is limited, causing low transpiration of the plant and therefore low nutrient absorption.
  - When the air humidity is too low, the stomates close, reducing the rate of photosynthesis.
- High humidity can also induce difficulties in pollination because wet pollen cannot be released.
- The humidity of the air in the plant area favours diseases.
- If the T° of plants falls below the dew-point T° of the air, water condenses on them and this encourages fungal development.

4.3.1 DEFINITIONS AND DEPENDENCY OF HUMIDITY

Humid air is a mixture of water vapour and dry air. The following values are used to characterize the content of water vapour in air :

- Relative humidity (R.H.) = $\frac{\text{actual vapour pressure}}{\text{Saturation pressure}}$ (%)

R.H. is defined as the ratio of the actual vapour pressure to the pressure that would result if the space was occupied by steam in saturation conditions, and is expressed in %.

R.H. is the most commonly cited characteristic of the air because it is easy to measure, but it has almost no significance unless the temperature is indicated.

- Absolute humidity = $\frac{\text{water vapour mass}}{\text{volume}}$ (kg/m^3)

Absolute humidity is the weight of water vapour in a given volume of atmosphere (air) and is expressed in kg of water vapour per cubic meter of dry air.

N.B.: Relative humidity and absolute humidity are dependent on the temperature of the air and vary with temperature. (At 15°C, 1 m^3 of air can contain 13 g of water and at 35°C, 39 g of water). In many cases they give an inadequate indication of climatic conditions in the plant area. If relative humidity is used to characterize the climatic conditions, the corresponding temperature must be mentioned.

- Water content = $\frac{\text{water vapour mass}}{\text{mass of dry air}}$ (g/kg)

The water content is independent of temperature.

- Plants react physiologically to:

Vapour pressure deficit (V.P.D.) = saturation pressure - actual vapour pressure.

- A similar measure is the :

Water content difference = water content at saturation - actual water content.

Note: For a given temperature, the vapour saturation deficit (V.S.D.) varies with the humidity of the air.

T°	Relative Humidity (R.H.) %	Vapour pressure V.P. (mm Hg)	Vapour pressure deficit V.P.D. (mm Hg)
20°	100	17.55	0
	80	14.04	3.51
	60	10.53	7.02
	40	7.02	10.53
	20	3.51	14.04

For 20°C and 60% R.H., the evaporative power is twice as great as at 20°C and 80% H.R. (V.P.D. : 7.02 and 3.51 mm Hg).

On the other hand, for the same R.H. (60%), the V.P.D. is 7.02 mm Hg for 20°C but 12.74 mm Hg for 30°C : the evaporation rate is, therefore, twice as high for the same R.H. (60%) for 30°C and for 20°C.

Similarly, if the air T° is 20°C and its R.H. 60%, its V.P.D. is 7.02mm Hg; if the air T° is increased to 30°C (for the same absolute water content of the air), the V.P.D. increases from 7.02 to 21.32 mm Hg; thus the evaporation rate is tripled.

- The dew-point temperature is the limiting point for condensation. The difference between dew-point temperature and actual air temperature is the dew-point difference. The higher the dew-point difference, the lower is the danger of water condensation on plants.

Discussing the relative humidity in greenhouses, it is necessary to consider how this factor varies naturally in response to the various conditions prevailing.

If the air mass in a greenhouse is maintained at some temperature above the temperature of the surface of the covering material, the relative humidity is less than saturated. The problem can easily be illustrated on a psychrometric chart as shown in Fig. 79. In this example, air of (a) (21.1°C and 90% relative humidity) is cooled down to 10°C. Below 17.5°C (b) dehumidification occurs (bb'). If the same air is then reheated up to 21.1°C without moisture addition, the relative humidity is 49% (C).

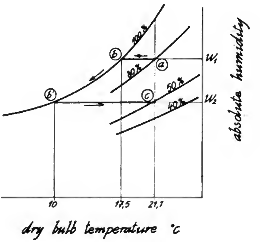

Fig. 79: Schematic psychrometric illustration of dehumidification and cooling, and subsequent reheating

If the moist air of a greenhouse in immediate contact with a cold surface is cooled below the dew-point temperature of the air, condensation will occur : condensation first occurs on the coldest surfaces, e.g. condensation on plastic covering material even during the day in closed greenhouses if the outside T° is lower than the inside one. As a result, dehumidification is observed in the shelter.

There appears to be no difference in relative humidity of air between plastic greenhouses or glass-covered ones, if sufficient ventilation is provided. The difference is that droplets form on plastic material while condensation under glass occurs in the form of a water film. The high level of humidity concentration in the form of droplets on plastic greenhouses has been considered as the major disadvantage restricting general acceptance.

4.3.2 INFLUENCE OF HUMIDITY

Condensation has been found to reduce significantly the thermal transmittance of some covering materials such as polyethylene, due to absorption of the radiant heat losses. The reduction of radiant heat transfer is not complete because the water film on the plastic film is not continuous and an area exists between drops which is free of condensation. Experimental data indicate that the effective area occupied by droplets is 70% for heavy condensation and 25% for light condensation. Condensation is light or non-existent in areas where air movement due to circulation fans is highest.

In some conditions (nights with clear sky) the air temperature in greenhouses drops suddenly after sunset due to high heat losses by radiation and before condensation forms on the covering materials. High humidity condensation can be responsible for a large transfer of heat to covering materials.

When the relative humidity in a greenhouse approaches the saturation level, problems of leaf disease are generally encountered, but below 75% of R.H. problems of infection are minor. In an experiment to compare the incidence of fungal diseases of tomatoes treated in three ways : a) no control of R.H.; b) control at 90% of R.H. and c) control at 75% of R.H., considerable infection by Cladosporium fulvum occurred in the crop with no humidity control, much less infection occurred where R.H. control action was initiated at 90% of R.H., and there was hardly any disease in the 75% R.H. treatment. Similar results were observed in the incidence of Botrytis cinerea.

It was also observed that, in tomato, problems of abnormal fruit colour development, fruit cracking and fruit spotting are associated with bad pollination owing to high relative humidity.

It was also found that low relative humidity in greenhouses adversely affects flower fertilization in tomato, muskmelon and beans, inducing flower abortion, and causes bitterness in cucumber fruits.

Growth chamber experiments in which only the humidity factor changed have shown that a humid atmosphere can generate a considerable rise in soil-water efficiency but also in morphogenic modifications. It was also observed that, in a humid atmosphere, the leaf area is often reduced, the vegetative storage organs develop later or not at all, flowering and fruiting are delayed, foliage senescence occurs earlier and stomates remain open longer, permitting continued diffusion of CO_2.

4.3.3 CONTROL OF HUMIDITY

The major factor regulating humidity within unheated greenhouses during cold weather is the condensation which occurs on internal cold surfaces. If no additional moisture is added to the air mass (during cold nights) condensation will result in a lowering of the absolute humidity. If the air mass is maintained at some temperature above the temperature of the surface, the relative humidity will be less than saturated. This problem is illustrated in Fig. 79. From experiments made in the USA it appears that the humidity in a greenhouse is normally under 90% during cold weather periods due to the condensation potential of the cool glazing surfaces. This remains to be proved in Mediterranean area conditions.

Quite often condensation forms on plants, causing infection and spreading diseases.

In heated greenhouses this can be avoided by:

- increasing air and plant temperature;
- improving the distribution of heat between plants;
- using thermal screens;
- installing water-saving irrigation systems ...

In unheated plastic greenhouses, condensation on plants and on the covering materials can be reduced as follows :

- to increase plant T°, covering materials with a lower long IR transmissivity or a double-film cover can be used;
- to reduce the absolute humidity of the air, plastic mulch and drip (instead of furrow) irrigation may be applied;
- to avoid dripping on the plants, a double cover or a single wall treated with an "anti-drop" product will do;
- to reduce the zones of high air humidity, it is possible to defoliate the bases of the plants (tomato), to improve air circulation, and to heat the air between the plants (hot air blown through perforated tubes);
- to maintain permanent air exchange between inside humid air and outside drier air in order to reduce moisture inside the greenhouse, ventilation during the night can be applied even if heat losses are caused by air exchange and water evaporation.

In **warm weather** the humidity problem can be defined as three distinct different problems:

1. High humidity at night when no solar heating is available and when the external temperature is near or above the desired interior temperature.

2 High humidity conditions when solar heating is available, but not sufficient to require ventilation.

3. Low humidity when solar heating is adequate to require ventilation.

The relative humidity in greenhouses tends to rise to saturation levels when the outside air temperature approaches or exceeds that of the inside air and condensation potential is lost. Under such conditions the relative humidity is controlled by ventilation until it falls below the required level.

When the outside air has a high level of relative humidity, ventilation must be complemented by artificial heating. It has been calculated that **every increase in air temperature by one degree generates a drop of about 5% in relative humidity.**

During warm weather the relative humidity in greenhouses often falls below the desired levels. To increase it, the following techniques are used:

- shading (a decrease of air temperature is accompanied by an increase of relative humidity);
- spraying soil, plants and glazing materials with water : a two-fold benefit is derived : humidity rises and the temperature decreases;
- improving air movement : evapotranspiration and relative humidity both rise (closed greenhouse);
- using fan and wet pad system : water evaporates and relative humidity rises;
- burning gas to produce CO_2 : moisture is released;
- using fine mist, besides cooling by evaporation : relative humidity is increased.

4.4 CARBON DIOXIDE (CO_2)

CO_2 is widely regarded as the most important nutrient for plants since the latter contain some 44% of C and a similar amount of oxygen.

The only source of CO_2 for a plant is air with a CO_2 content that does not exceed 0.03% (300 ppm).

To make up 10 g or so of dry material per m^2 per day, a tomato crop consumes some 2 litres of CO_2, which – approximately – corresponds to the result of the combustion of 0.03 m^3 of natural gas (i.e. about 30 m^3 of gas/hour/1000 m^2 of crop). Basically this looks a trifle !

It is not clear however why so little importance is attached to the so-called "carbon nutrition", especially as the speed of plant growth is generally known to decrease sharply when the minimum concentration of 300 ppm fails to be reached whereas most plants are known to yield much more when the available CO_2 concentration exceeds this level of 300 ppm. It is generally estimated that the growth rate of tomatoes under "normal" light conditions decreases by 80% when the available CO_2 falls down to 100 ppm and increases by 20% when it reaches some 1000 ppm.

Furthermore, it must be kept in mind that in the case of tomatoes grown in an airtight greenhouse, the CO_2 level falls in the morning, right from sunrise, from 300 ppm down to under 100 ppm in less than 2 hours.

Even when the greenhouse is ventilated naturally, the level of CO_2 falls below 300 ppm as a result of the absorption of carbon dioxide by the crops: for tomatoes it seems to stabilize at around 200 ppm within some hours.

The technical literature produces similar values for cucurbitaceae. It also mentions different relations between the available light intensity and the quantity of CO_2 absorbed by plants. Only one value is worth mentioning here : in the case of tomato, 1500 lux – i.e. a fairly low level of lighting – would suffice to "use" the 300 ppm of CO_2 contained in the air: above this light level, the growth of plants would most probably benefit from any supply of CO_2.

It has also been said that CO_2 is to be supplied even when insolation is low, "the increase in CO_2 being a substitution for the lack of light". Actually, there seems to be another way to explain the interest of supplying CO_2 even when light level is low : any increase in the concentration of carbon dioxide gas would make this more accessible to the plant, i.e. would facilitate the exchanges between the outside air and the sub-stomate cavity.

The problem of CO_2-enrichment in the Mediterranean region can be set as follows: as soon as the sun rises (as soon as it is daylight), whether the greenhouse is open or not, CO_2 becomes scarce and the plants (such as tomatoes) do not photosynthesize at their optimum rate. The extent of the depletion increases with the degree of air tightness of the greenhouse and also depends on how long the latter remains closed : the plants risk becoming unable to reach their compensation point within a very short time. This means that they respire faster than they photosynthesize.

CO_2 supply is a serious problem : whether the greenhouse must be opened or can be closed, the possibility of supplying CO_2 should always be a real one.

Research should be oriented towards the discovery of a method to supply CO_2 economically during a sufficient span of time, i.e. at least every morning rather than based on the determination - as prevails in industrialized countries - of the optimum rate of CO_2 (600, 900, 1200 ppm?). Moreover, growers should be made aware that crops need CO_2 fertilization as badly as they need N, P, K... even when the greenhouse is ventilated!

Though authors do not seem to agree fully on the subject, it thus seems that CO_2 supply is always a source of improvement of crops - even in market gardening. It remains to be found whether CO_2 may be supplied ECONOMICALLY, i.e. whether the costs of supply, considering the conditions prevailing in the Mediterranean region, are offset by an increase in output whatever the crop grown.

Contrary to European practice, the Mediterranean greenhouse does not appear to need CO_2 sensors or regulating devices : such equipment is far too expensive (nowadays - 1985 - a "medium-sized" sensor costs about US$ 1 000).

Anyway, more often than not, growers are bound to face technical problems, and the least of them is surely not related to electric power supply.

Greenhouses should therefore be fitted with small burners running on pure fuels and therefore releasing only CO_2 and H_2O. Furthermore, it should be remembered that the fermentation of the straw placed in the furrows emits by no means negligible quantities of CO_2.

No solution is likely to be worked out that can suit every particular case and every country since the purity of the products available is not homogeneous or simply because the same products are not to be found everywhere. However, it should be kept in mind that, since CO_2 depletion is most serious when the greenhouse is closed, i.e. when the outside temperature is relatively low, shelters could profitably be fitted with small fuel-oil or butane gas burners. The heat provided cannot but help create more favourable cultivation conditions. In other words, CO_2 supply is not to be taken for itself but as a "by-product" of heat, either technique increasing the profitability of the other.

CHAPTER 5

PRODUCTION MEANS AND TECHNIQUES

5.1 SOIL AND SUBSTRATES

In the Mediterranean region, the subject covers two different aspects:

- The first refers to the **natural soils** which, contrary to the present trend in central and northern Europe, seem to be used for the great majority of protected crops. In fact, up to now, these soils meet the needs of protected cultivation essentially in plastic houses.

These conditions are: climate, characteristics of the soils in situ, rather extensive cultivation systems, economic values of the yields, technological level, requirements of the crops, etc.

- The second topic deals with the possible use of more or less inert **substrates** - already widespread in the north of Europe - to develop cultivation systems (up to soilless cultivation, hydroponic or aeroponic growing..) without the limitations of natural soils.

Systems like these prove particularly useful for the growing of some particular crops (e.g. some flower species) and therefore can certainly help to improve protected cultivation in the Mediterranean region.

The problem of **substrates for nurseries** is becoming increasingly serious. Though they do not have the necessary organic material at their disposal, some Mediterranean regions have been compelled to refuse the importation of too expensive substrates which frequently fail to satisfy local users.

5.1.1 NATURAL SOILS

The natural soils (see § 2.2) are widely spread in the Mediterranean region but they can seldom be said to offer the most suitable conditions for protected cultivation.

Therefore, every soil needs to be managed carefully if it is to satisfy the high requirements of protected crops. This is achieved more easily in a soil that contains 50-60% of sand, 12-20% of silt, 10-15% of clay and 6-8% of organic matter.

Favourable combinations of hydrological and physical characteristics are found in soils with a balanced texture (see Table 14).

Table 14 Some physical and hydrological characteristics of different soils (from ANSTETT, 1979)

Soils	Dry bulk density	Field moisture capacity		Available moisture	Values (mm) of some hydrologic parameters for a volume of soil 500 mm deep		
	(g/cm^3)	(% weight)	(% volume)	(% volume)	field capacity	wilting point	available moisture
Sand	1.35	10	13.5	11.0	67.5	12.5	55.0
Silty-sand	1.30	16	21.0	18.0	105.0	15.0	90.0
Sandy-silt	1.25	20	26.0	21.5	130.0	27.5	107.5
Silt	1.20	29	35.0	24.5	175.0	52.5	122.5
Silty-clay	1.15	33	38.0	22.5	190.0	77.5	112.5
Clay	1.10	38	42.0	22.0	210.0	100.0	110.0
Peat	1.00	70	70.0	40.0	350.0	150.0	200.0

Most of the Mediterranean protected cultivation lies along the coastal zone where sandy-textured soils are of course much more frequent than heavy ones, with the result that the main difficulties to overcome are high permeability, low capacity for water retention and for cation exchange (often less than 10 meq/1).

This area is also characterized by high degrees of alkalinity or salinity and is low in organic matter (often less than 1%) and in nutrients.

Nevertheless, sandy soils offer several advantages since they warm up rapidly, are easy to till, do not greatly interfere with root-water-soil relationships are never wet and may have properties that keep down some diseases.

In protected cultivation, the usual agronomic practices are not sufficient; the soil needs special preparation and management, e.g.:

- enrichment with organic matter in order to improve the texture and correlated characteristics;
- control of the nutritive conditions, of alkalinity and/or salinity;
- control of biological conditions to counteract the presence of pests and diseases in the soil.

The **organic matter** content is very difficult to enrich in Mediterranean regions because of the scarcity and the high price of manure, the rapid mineralization of humus under high temperatures and the subsequent modifications of the soil.

Peat could be efficacious in heavy soils (Table 15) as well as in sandy ones, but it fails to be a real alternative in Mediterranean regions as a result of its price. Moreover, using it in soil conditioning is a source of other problems such as the anomalous raising of the C/N ratio, a further accentuation of porosity in sandy soils and a possible dehydration difficult to offset.

Table 15 Effects of adding peat to a silt-loam soil on some physical and hydrologic characteristics (based on data from HANAN et al., 1978)

Silt loam-peat proportion	Bulk density (g/cm³)	Total porosity (% volume)	Air (% volume)	Moisture capacity(1) (% volume)	Percolation rate (cm/h)
10 : 0	1,15	57,0	13,1	43,9	4,1
9 : 1	1,05	60,7	17,0	43,7	4,6
7 : 3	0,93	64,9	23,9	41,0	39,1
5 : 5	0,69	73,4	25,8	47,6	99,6
3 : 7	0,48	81,1	23,8	57,3	148,3
1 : 9	0,22	91,1	22,5	68,6	>152,0
0: 10	0,10	94,4	30,6	63,8	>152,0

(1) determined for a column 17,2 cm deep

Consequently, growers have to turn to other elements like **residual products of agriculture** (grape stones, olive husks and other crop residues). Montomorillonitic clay soils are useful to reduce the amount of organic matter necessary to condition the texture of very sandy soils.

The addition of organic matter also helps to improve the chemical condition of the soil and to increase its cation exchange capacity.

On the other hand, in sandy soils, the only way to ensure that the crops make the best use of the nutrients and water which they require is to provide them with **small but regular doses** of fertilizers and to apply a **drip irrigation** system. These two principles reduce the percolation rate, the leaching and in some conditions, avoid a salt accumulation.

Salinity is a characteristic of the coastal regions where salt build-up is the natural result of insufficient leaching. This situation can be avoided by small volume irrigations, tillage and mulching in order to hamper the upward movement of the saline water located in the deeper layers. Problems of salinity related to fertilization can occur in greenhouses where the permanent cover prevents leaching by rainfall.

Some local techniques prove efficient, e.g. the **"enarenado"** system practised in southern Spain (Murcia, Almeria, Malaga). It consists from bottom to top, of:

- a 30 to 40 cm-thick impermeable layer of clay soil;
- a 1 to 2 cm-thick layer of manure;
- a 10 to 12 cm-thick silicious sand layer.

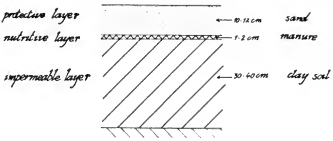

Fig. 80: Schema of the "Enarenado" system

The root system of the crop develops in the manure layer, the bottom of the sand layer and the surface of the clay soil. The latter being impermeable does not allow any downward movement of the water, which decreases the watering demand, nor any upward movement of the same, which prevents the rise of salts from the underlying soil. The manure layer, which supplies the nutrients, is renewed every 4 to 5 years.

The sand reduces evaporation, prevents weed development, improves aeration in the root environment and increases the substrate temperature.

The "enarenado" technique is a simple way to achieve intensive production of crops sensitive to salinity on poor soils located in arid zones whilst using less water and even poor quality water.

Considering the biological conditions of the soils in greenhouses, weed control is no real problem there, especially as plastic mulching keeps down weeds.

By contrast, **soil-borne pests and diseases** require rigorous control since, even in the Mediterranean region, they put greenhouses under constant threat. Yet, such control is not easy since solutions like grafting, soilless cultivation (on growing media different from in situ soils) are seldom compatible with the technological level of the Mediterranean protected cultivation; moreover, methods such as steam sterilization do not always prove efficient. **Chemical sterilization**, in particular with methyl bromide, remains the only alternative, but this product is a dangerous one because of the risks of pollution of the environment it represents and owing to its possible accumulation in crops. **Nematodes** deserve particular attention since they can develop in great numbers under Mediterranean climatic conditions.

A **transparent plastic mulch** over the soil during the warmest months of the year offers a partial control of soil-borne pests and diseases. Indeed, it brings the temperature of the soil up to a level sufficient to kill some of the microorganisms and to improve the biological conditions of the soil (cf. "Solarization" - § 5.4). Solarization has proved sufficiently efficient, in spite of its limits, to be recommended on the eastern and southern shores of the Mediterranean Sea; it is economical and, above all, devoid of any danger.

5.1.2 GROWING MEDIA

Growing media as distinct from the soil in situ may theoretically improve protected cultivation in the Mediterranean region as they offer technical advantages far from negligible, as for instance:

- control of soil pests and diseases;
- better use of irrigation water and fertilizers;
- more intensive utilization of greenhouse space;
- ability to meet the requirements of the plants, etc...

However, the use of growing media is problematic, at least for vegetable crops, for the following reasons:

- **availability, cost and characteristics of the media**: The Mediterranean region has no peat at its disposal and transport charges are quite prohibitive. Besides, some handicaps are inherent in the material itself when submitted to the hot climate of the Mediterranean region, e.g. moisture levels can hardly be maintained and the chemical and physical characteristics of black peat undergo rapid modifications;
- **the technologies needed** to carry out cultivation without natural soils are absent locally;
- **the production system is rather extensive**: plastic-covered greenhouses are frequently not climatized; the cultivation is restricted to vegetables; the crop sequence is broken;
- **the climatic conditions** inside and outside the greenhouses vary considerably in the course of time, making it difficult to maintain the growing media at a temperature suitable for water and nutrient absorption by the roots.

The same reasons explain why other cultivation systems (hydroponic, aeroponic, vertical culture (*) etc.) are difficult to carry out in Mediterranean countries. These systems are subject to conditions (technical, economic and social) difficult to achieve and are sometimes uneconomical.

All this leads us to conclude that the only interest for vegetable crops in protected cultivation lies in the simplification and adaptation of the easiest cultivation system (NFT = Nutrient Film Technique) to the existing production pattern.

(*) This theme will not be discussed here.
Please refer to the FAO Plant Production and Protection Paper, No. 101, "Soilless Culture for Horticultural Crop Production"

5.1.3 SUBSTRATES FOR NURSERIES

Since the use of selected plant material of high cost, such as hybrid seeds, has become widespread, and since protected cultivation has high input requirements, the need to produce good quality plants in well managed nurseries has increased. Therefore, the use of substrates other than the natural soil is recommended in order to:

- obtain favourable growth conditions
- improve control and production organization
- reduce the cost
- allow for mechanization
- increase yields

However, the use of artificial substrates requires more skill and knowledge than the use of the soil, and therefore, a good understanding of their characteristics is a prerequisite.

5.1.3.1 Characteristics of a good substrate

An adequate substrate should meet the following requirements:

- to hold and supply large quantities of water, thus allowing wide irrigation intervals;
- to retain a stabilized structure throughout its period of use, and a known uniform texture in order to store large volumes of air for good root aeration even in the event of excessive irrigation;
- to adsorb and retain plant nutrients in an available form, and have a good buffering capacity in order to compensate for any excess or deficit of nutrients;
- to be chemically inert;
- to be biologically inert.

Wherever possible, **the use of manures should be avoided** owing to their variable quality, their heterogeneity, the difficulty of controlling their microbiological decomposition, the variations in their nutrient content, and their possible infections.

Their characteristics are a result of the physical properties of the substrate. They depend on the structure of the components, and are defined by the ratio between large and small-sized particles, the pore system, and the relative volumes of air and water present in the pores.

It is advisable to know the following **physical parameters**:

- granulometry, size and proportion of particles;
- bulk density, weight-to-volume ratio, including pore volume;
- average density of particles, pore volume not included;

- total porosity, % volume of pores, filled with air and water, in the total volume;
- solid material (% vol.), by difference; 100 - total porosity;
- air content (% vol.), difference between total porosity and water volume measured at 10 cm tension;
- easily available water (% vol.), difference between water volumes at 10 and 50 cm tension;
- reserve water (% vol.), difference between water volumes measured at 50 and 100 cm tension.

It is also important to know the chemical characteristics of the substrate in terms of the parameters:

- . pH
- . cation exchange capacity (CEC)
- . soluble salts content.

It is possible to define the ideal picture of a substrate as follows (see Fig. 81):

. bulk density	0.22 g/cm^3
. particle density	1.44 g/cm^3
. total porosity	85%
. solid material	10-15%
. air content	20-30%
. easily available water	20-30%
. reserve water	6-10%
. pH	5.5-6.5
. cation exchange capacity (CEC)	10-30 meq/100 g dry weight
. soluble salts content	200 ppm (2 mmhos)

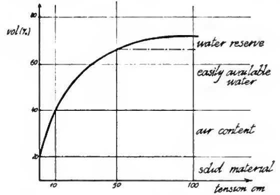

Fig. 81: Water retention curve of an ideal substrate (*)

(*) PAGES M. & MATALLANA A. (1984). "Caracterización de las propiedades físicas en los sutratos empleados en horticultura ornamental" - Comunicaciones INIA, Ser. Prod. Veg. N°61, Madrid.

5.1.3.2 Characteristics of some substrate materials

There exists a wide range of good quality products, and the choice between them depends on the availability, cost and local experience.

A. Organic products

1. Peat. Three different types can be considered:

- Sphagnum moss peat, or "peat moss", is the least decomposed peat type. It gives excellent air/water properties to the medium, has a low pH, and low N content.

- Reed-sedge peat varies in its stage of decomposition and acidity.

- Peat humus is a highly decomposed material, black or dark brown, with low water retention capacity and medium to high N content.

The organic matter content of a peat should be over 80% on a dry weight basis. Most peats have a low ash-content, often less than 5%; this means that they contain relatively small amounts of nutrients apart from N.

Peat moss contains 80 to 90% of organic matter and 4 to 20% of ash. The cation exchange capacity (CEC) ranges from 60 to 120 meq/l.

Peat humus contains around 50% organic matter due to its high decomposition, and some 50% ash, which means a high mineralization stage. The CEC is from 250 to 350 meq/l. Peat humus coming from saline areas is not recommended.

Other beneficial components are present in peats, for instance humic acids, acidoids, fulvic acids.

Why is peat an interesting component of a substrate ?

- it increases the water capacity;
- it increases porosity, which gives better aeration and better drainage;
- it decreases soil volume weight and thereby facilitates plant root development;
- it increases the buffering effect, which keeps pH and soluble salts at convenient levels;
- it is a slow N releasing source;
- it improves the availability of nutrients to the plants.

The commercial peats may not always be free from problems; some rehydrate with difficulty, therefore seedlings on these substrates require particular attention as to water supply and overdrying of soils must be avoided.

2. Leaf mould consists of organic debris, of variable composition and heterogeneous size, that lay on the forest floor. It can be used either directly or after composting. The organic matter-content is around 60%, and the ash-content about 40%.

3. Wood wastes: various wood wastes from the wood and paper industry are suitable substrates: sawdust, compost bark, pine chips, shredded pine bark...

Two major problems must be taken into account with these products:

- Firstly, their high C/N ratio causes a high immobilization of N from the growing medium that can produce N deficiency. This can be solved either by adding slow release N fertilizers or by composting. The addition of 1 kg/m^3 of NH_4NO_3 or 2 kg/m^3 of a 20-10-5-6 slow release fertilizer can be recommended.
- On the other hand, wood wastes can contain phytotoxic compounds that inhibit germination and growth when fresh, and so it is convenient to store and compost them for some time before use. A composting time of some 5 months could be necessary to eliminate the phytotoxic action of some hardwood wastes.

Composted bark or sawdust supplemented with nutrients can be a useful substitute for peat in substrate mixtures. Composting is done with the addition of N, under aerated conditions, at temperatures up to 60-70°C.

The CEC of a composted pine bark is 100 to 150 meq/l.

4. Wool waste is a by-product of industry that can be used directly without any other preparation. It contains 50% of organic matter and 20% of ash.

5. Grape marc must undergo an aerobic fermentation before use. It contains some 90% of organic matter and 10% of ash.

6. Olive marc can be used as a substrate after 4 months of composting. In fact, a two-month composting time is enough from the physical viewpoint, but another two months are needed to reach a complete decomposition of the phytotoxic compounds, mainly of acetic acid. Furthermore, after two months' composting, the toxic compounds can be removed by leaching with water. Olive marc has a slightly higher pH than is desirable, but its electrical conductivity is acceptable. Total N-content is above 1.2-1.5%. Mixing the material with physical conditioners results in a better substrate.

7. Rice shells are used directly. They have some 87% of organic matter and 13% of ash.

8. Other interesting organic residues which can be used as substrates are: sugarcane bagasse, dry coffee leaves, coffee parchment, water hyacinth roots,, seaweed "leaves", cork oak waste...

B. Inorganic products

1. Clay is beneficial in a substrate medium because it consitutes a reservoir of nutrients and water, is a source of trace elements and improves the buffering capacity and the pore quality of the mixture. The CEC of a soil with 30% of clay is 200 to 300 meq/l.

2. Sand generally decreases the porosity of the growth medium. Sand porosity is around 40% of the bulk volume. The sand particles should be 0.5 to 2 mm in diameter. It contains no nutrients and has no buffering capacity. The CEC is 5 to 10 meq/l. It is used together with organic materials.

3. Volcanic soil, expanded clay, and puzzolan are also useful materials to increase the air-content of a substrate; but they have a lower density than sand. They are also very low in nutrients, and their buffer capacity and CEC are negligible.

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4. Vermiculite has a structure able to hold and release large quantities of water, which reinforces similar properties in peat when mixed. It is neutral in reaction and has a relatively high CEC of 80-120 meq/l to reduce loss of N, P and K by leaching. The main disadvantages of this material are the high cost and the easily breakable structure which can lead to compression of the substrate.

5. Perlite is used as substrate structure conditioner. In contrast to vermiculite it is totally inert, has low CEC or buffering capacity and low water retention. It supplies air space to the medium and permanence due to its unalterability. It is neutral in pH, very light in weight, a good temperature stabilizer, and favours healthy growth because of the greater air content. Possible disadvantages include risk of Al toxicity in some seedlings at low pH, also the limited capacity for water supply under conditions of high transpiration, resulting in the need for frequent irrigation.

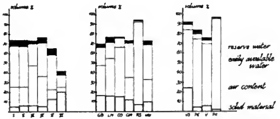

Fig. 82: Physical properties of substrates

I, II : German peat moss
III : Russian peat moss
IV : Canadian peat moss
V, VI : Spanish black peats
CB : composted pine bark
LM : leaf mould
CO : cork
GM : grape marc
RS : rice shell
WW : wool waste
VS " volcanic soils
PE " perlite
V " vermiculite
PX " porexpan.

(From PAGES M. & MATALLANA A., 1984, op. cit.)

C. Synthetic products

1. Expanded polystyrene ("Porexpan" or "Styromull") in 4 - 12 mm diameter particles is an inert and stable material of neutral pH that improves the aeration and drainage of the substrate. It does not retain water or nutrients, but is ideal for plants that need good root aeration.

2. Urea-formaldehyde expanded resin. It contains slow-release N, improves drainage and can retain a certain amount of water, but it can also produce phytotoxic effects.

These materials are normally added to mixtures in proportions not higher than 30 to 50%.

5.1.3.3 **Suitable mixed substrates**

A basic principle for substrate preparation, especially if large amounts are required, is that the formulation must be simple; indeed, the multiplication of components increases the risks of faulty preparation and of mishandling.

As previously stated, it should be kept in mind that the physical properties of the substrates differ appreciably from each other, and the surest way to correct the unfavourable characteristics of any one of them is to combine them. So, for example, the poor aeration capacity of a highly decomposed black peat or of a clay soil which, on the other hand, have an appreciable water retention capacity, can be corrected by materials such as sand, polystyrene, perlite or expanded clay, whose common characteristic is to increase aeration.

The addition of lime is useful to adjust the pH of a substrate. When peat is to be mixed with other inert materials, its pH should be corrected before the peat is incorporated. Furthermore, the correction should be made before seeding or planting because it would be difficult to achieve afterwards. The proportion of lime to be added depends on the initial and final pH levels, on CEC (the higher this is, the greater the amount of lime required for the same pH level), and on the types of fertilizer used.

A black peat with high CEC and a pH of 4.5 needs 4 to 5 kg of lime/m^3 to reach pH 5.5. A peat moss with lower CEC and pH 3.5 needs some 3 kg lime/m^3 to achieve a pH of 5.5.

The composition of the substrate may vary considerably depending on the materials available, the requirements of the crop, and the way in which the substrate is to be used. When pressed blocks are prepared, the danger of drought is greater and thus the mixture should have a higher water retention than if plastic pots are used, the walls of which are impermeable and thus reduce moisture losses. Furthermore, pressed blocks need sufficient cohesion to retain their shape. The blocks should have a minimum of 10% of air for good aeration. Mixtures of peat and lime-free sand (75% + 25% vol, or 50% + 50% vol.) give good results in the nursery and allow a good control of watering. Sand is much cheaper than peat, but it is poor in nutrients, and some should be added; for example superphosphate 18%, 780 g/m^3 and potassium nitrate 400 g/m^3, in addition to the appropriate pH correction. Other useful mixtures are soil 15% (vol.) + peat 50% + perlite 35% or peat 60% + sand 25% + soil 15%, fertilized with 2 to 3 kg/m^3 of a complete fertilizer (15-15-15).

Peat is often replaced by other organic substrates as listed in paragraph 5.1.3.2 and locally available. The following figures give some summarized information on various mixtures.

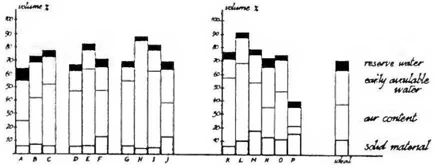

Fig. 83: Physical properties of substrate mixtures

A : 75% peat + 25% vermiculite;
B : 75% peat + 25% perlite;
C : 75% peat + 25% porespan;
D : 50% peat + 50% vermiculite;
E : 50% peat + 50% perlite;
F : 50% peat + 50% leaf mould;
G : 25% peat + 75% vermiculite;
H : 25% peat + 75% perlite;
I : 25% peat + 75% porexpan;
J : 25% peat + 75% composted pine bark;
K : 50% peat + 25% vermiculite + 25% perlite;
L : 50% composted pine bark + 25% peat + 25% vermiculite;
M : 50% composted pine bark + 50% volcanic soil;
N : 50% composted pine bark + 50% leaf mould;
O : 33% composted pine bark + 33% peat + 33% leaf mould;
P : small pressed block 50% peat + 50% soil

IDEAL: theoretically ideal substrate.
(From PAGES M. & MATALLANA A., 1984, op. cit.)

5.2 FERTILIZATION

In many vegetable production areas, fertilization used to be traditionally associated with the incorporation of organic matter - usually cattle manure - into the soil. It was used not only as a corrective to improve the physical properties but also as a source of nutrients. Most manures are quite rich in P and K and the mineralization of organic matter, very fast at high temperature, could provide a uniform supply of nitrate nitrogen.

However, manure shortage, increasing prices and the presence of weed seeds have decreased its importance nowadays. At the same time, new technologies, such as drip irrigation and fertirrigation, supplying water and nutrients almost continuously, have reduced the importance of the organic matter content of the soil, which is becoming just a support for the crop root system.

In protected cultivation the cost of fertilizers is a relatively small part of the gross production cost; productivity is very high and the roots only exploit a small volume of ground. So the content of nutrients in the soil may be ignored and fertilizer supply calculated only according to plant needs. When no detailed information about nutrient requirements for a specific crop is available, the use of a nutrient extraction table (Table 16) is a good way to start and to calculate the right NPK balance and the amount of fertilizer that should be applied.

Table 16 Approximative absorption of nutrients by several crops under protected cultivation

CROPS	Yield (t/ha)	Extraction in kg/ha of :				
		N	P_2O_5	K_2O	CaO	MgO
Tomato	80	250	80	500	300	70
Sweet pepper	40	180	60	180	160	50
Eggplant	50	250	40	300	150	25
Muskmelon	60	230	80	400	300	70
Cucumber	200	320	160	600	250	100
Summer squash	40	170	70	390	-	-
Lettuce	40	100	50	250	50	12
Greenbeans	45	150	15	60	30	6
Carnations	150*	1 200	300	1 100	-	-
Roses	80*	150	30	100	-	35

* flowers. m^{-2}.

These values need not be modified because of a variation of yield. Indeed, the leaves and the roots absorb the same element, but in a different way.

But several **remarks** command attention:

1. **The nutrient uptake varies during the cropping cycle** as to the amount and the type of mineral elements, e.g. young plants have a lower requirement and usually prefer a higher N/K ratio; after transplanting, plants react well to P.

2. **The climate can influence nutrient equilibrium**, e.g. in wintertime with low light situations the N/K ratio should be lower than in summer, to reduce plant etiolation; low soil temperature inhibits phosphorus absorption.

3. Generally, **plants need less nutrient** (for the same yield) **under shelter** than in the open air (better absorption of nutrients).

4. **The P-absorption depends on the soil temperature**; but it is not advisable to increase the amount of P given when the soil is cold (spring); it is better to increase the soil temperature before planting (mulching 1 or 2 weeks beforehand).

5. **The uptake of a nutrient depends on its concentration** in the soil solution. Plants may absorb some of them in excess if the concentration is too high. For instance, if nitrogen application on lettuce exceeds 200 kg. ha^{-1}, growth does not increase proportionally but only the N content of the leaf, which may result in some nutritional problems.

6. **An excess of nutrients** can have detrimental effects such as phytotoxity or abnormal growth excesses. For example, excessive boron results in plant death or excessive nitrogen can cause luxuriant leaf growth at the expense of flowers or fruit.

7. The application of nutrients to the soil **in the exact proportions** needed by the plants does not necessarily give good results, because they may not be all absorbed in the same way. For instance, it is usual to apply more phosphorus than that extracted by plants.

8. The application of nutrients should be **proportional to plant uptake** to avoid any antagonism between nutrients. For instance, the detrimental effect of high potassium application on magnesium absorption is well known.

9. When rather **saline water** is used for irrigation, its nutrient content may, in certain conditions, be important with regard to plant nutrition. This is particularly true if the irrigation water has a high content of calcium, magnesium, boron or sulphur, for instance.

Nutrient absorption by plants is difficult to control because many soil factors are involved; e.g. pH, temperature, exchange capacity, salinity, water supply. However, **two methods may be used** to build a fertilization **programme** with sufficient precision: soil analysis and plant leaf analysis.

- If **soil analysis** is carried out, using water as the extractant instead of ammonium lactate, for instance, information about the content of nutrients in the soil solution is obtained, but not about the potential nutrient reserve. It is possible, therefore, to make an accurate estimate of the amounts of nutrients readily available to plants.

When a new crop is being planted, the soil should be in relative equilibrium, i.e., it should have an average content of nutrients calculated according to the methods described above. In addition, soil analyses will be made periodically throughout the cropping cycle.

It is also possible to test the fertilization programme by knowing the nutrient balance in the soil.

If the content of a certain nutrient increases, its application should be reduced and vice versa. In this way, the soil is considered as a nutrient reservoir whose level must be kept constant.

- **Leaf analysis** is complementary to soil analysis, for checking plant composition in nutrients. Using it shows whether nutrients are being absorbed although they are present in the soil. Standards for leaf nutrient content do not vary much from one region to another, so figures from other regions may be used. However, the amounts of fertilizer that must be applied to obtain the correct leaf content vary widely, depending on growing conditions. So it is necessary to adjust a fertilization programme to each crop and region.

Values not checked by the methods described above should not be relied upon. This can be a big handicap for regions or countries without appropriate Research and Experimental Development programmes.

This means that it is difficult for growers to use fertilization recommendations in relation to leaf analyses which have been established in other countries but not tested at home or under similar climatic or growing conditions.

Fertilizers with a high nutrient content are advisable in protected cultivation, otherwise it is necessary to apply large quantities of "normal" fertilizers to fulfil the crop needs with risks of soil salinization or Cl^- excess.

But the use of high purity fertilizers does not supply enough **minor elements**, so that specific application of micronutrients becomes essential under these circumstances. The best way to achieve this is by foliar spraying, since incorporation in the soil can give very uncertain results due to problems of precipitation and uptake.

For **macronutrients, various sytems** of **application** may be used. The traditional pre-planting broadcasting distribution, followed by several post-planting dressings, is incompatible with high crop performance and should be left only for situations where furrow irrigation is still used. If drip irrigation is available, liquid feeding (also called in the Mediterranean, fertirrigation or fertigation) is the recommended system, saving labour and allowing plants to receive water and nutrients at the same time.

A few points should be taken into account, such as:

a. the control of water salinity, particularly if soil drainage is not good;

b. phosphorus precipitation if the water is too alkaline;

c. the use of soluble fertilizers. If special liquid formulations are not available, it is always possible to formulate the correct NPK solution using potassium nitrate, phosphoric acid or ammonium phosphate and low biuret urea (urea with less than 1% biuret) (*).

Fertilizers can be supplied continuously in the irrigation water or concentrated at the end of the irrigation period. Both procedures are possible and the choice sometimes depends on the type of fertilizer injection system.

In order to reduce salt accumulation in the soil, small amounts of fertilizers applied frequently are better than large quantities at longer intervals.

Slow-release nitrogen fertilizers are another way of providing a nitrogen supply. These forms avoid loss of N by leaching and remain available to the plant for 2 to 3 months. Due to their high price, the use of these forms is only profitable for high value crops such as pot plants.

(*) Biuret is a rather phytotoxic chemical product which sometimes appears mixed with urea in high percentages, making it unsuitable for horticultural purposes.

5.3 IRRIGATION

Water is very important for plants because of its influence on various physical phenomena : nutrient uptake; transpiration and reduction of leaf temperature; metabolite translocation; photosynthesis and respiration (if stomas are closed owing to water stress, gas exchange in the leaf is reduced). Water is so important that for every crop there is a close relation between water absorption and dry biomass increase.

As a practical conclusion from this it may be said, that in many situations, **correct water supply is the easiest way to improve productivity.**

Protected cultivation is the best example of the importance of irrigation. Since rainfall levels are too low, water has to be supplied artificially. A greenhouse being a closed space, the irrigation system itself has a great influence on climate and can be one of the ways to control air humidity and soil temperature. So, the choice and management of the irrigation system deserve particular attention.

5.3.1 IRRIGATION SYSTEMS

Many systems are available, and the most frequently met in greenhouses are the furrow, sprinkle and drip irrigation systems. The preference given to some of them over others is more often than not dictated by economic reasons or reasons not bound to the characteristics of the farm itself (electricity power supply, availability of materials...) rather than by technical or social reasons.

5.3.1.1 Furrow irrigation

This traditional system is still widely popular with family smallholdings throughout many regions, but unfortunately its cheapness is heavily counterbalanced by too many defects :

- it does not supply water uniformly nor constantly;
- it lacks efficiency (relation between water supplied and water actually used by plants);
- in some cases, it brings air humidity in the greenhouse up to unacceptable levels;
- it excludes fertirrigation and automation.

There are many ways to **improve this technique** (*), and they all deserve due consideration:

- When the irrigation stand-pipe (only a limited pressure is required) is installed at the edge of the field, a black PE hose-pipe (0.40mm thick- 15 to 20 cm wide when flat) is useful to carry water from the

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(*) TABRESSE et al. (1980) "Cultures maraîchères au Sahel tunisien". AGCD; 1050 Brussels, 5, Place du Champs de Mars.

stand-pipe up to the plot which needs irrigating. The great advantages of hoses are that they can be rolled up easily, thereby facilitating removal, and that they prevent considerable water losses through an extended network of wide-section "seguias" (= "furrow" in North Africa). The hoses cost about US$ 0.2 per linear metre.

- Large seguias are carefully lined with 0.20-mm thick black PE film. The aim is to avoid water losses and weed invasion (cost : US $ 0.4 to 0.5 per linear metre). This technique prevails where the main seguias are connected to furrows (i.e. to the plots which need irrigation) through siphons (see below);
- The furrows dug between the rows of vegetables are connected directly to a slightly elevated main seguia through a number of siphons (2.5 to 3 cm in diameter), proportional to the length of the furrow. For water to be evenly distributed, such furrows must be filled with water for an equal span of time. This is achievable by regulating the flow running into each furrow (i.e. by providing the right number of siphons) and assessing correctly the length and the slope of the furrows (0.5 to 1% when possible).

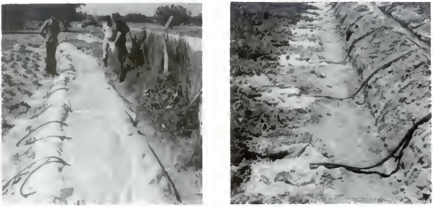

Fig. 84: Main seguia with siphons supplying furrows with water. (*)

- Lateral water infiltration is appreciable in heavy soils but less so in very light or sandy ones; consequently, furrows must be nearer to each other in light soils than in heavy ones;

(*) TABRESSE L. et al. (1980). "Cultures maraîchères au Sahel tunisien". A.G.C.D., 5, Place du Champ de Mars, 1050 Bruxelles.

- Moreover, the furrows may be dug at a very short distance from the plants when these are young and the distance may get greater as plants grow;

- The length of the furrows must suit the nature of the ground : the acceptable minimum length is 30 m and the maximum ranges from 50 m (sandy soil) up to 100 (heavy soil).

5.3.1.2 Irrigation by systems using water pressure

- **Sprinkler irrigation**

1. for crops not planted in rows, with a high number of plants per unit of surface, such as lettuce;

2. in situations lacking air humidity or for crops sensitive to air dryness, such as cucumbers and roses.

In these situations, the sprinklers may be placed above the plants or at ground level. The first alternative provides better humidification, but needs high quality water to avoid salt spots on the leaves. It must usually be supplemented by soil irrigation.

In practice this method requires water at a pressure of about 1 kg/cm². Sprinkler irrigation systems - devised for open air market gardening - give better results when mobile. Medium pressure nozzle fan sprinklers are fixed on small mobile units. In protected cultivation, the equipment is fixed permanently, which raises the costs per unit of surface.

Sprinkler irrigation in greenhouses presents some dangers in winter and in spring : spraying with rather low temperature water results in physiological damage (e.g. heat-demanding plants such as peppers risk dropping their flowers).

Among the various nozzles being used in greenhouses, the plastic ones are the most frequently met at present. Each type of nozzle has a characteristic curve showing its flow in relation to water pressure (*).

- **Mist irrigation**

This is a special case of medium pressure sprinkler irrigation in greenhouses.

It is mainly intended to regulate the humidity of the atmosphere of the greenhouse and - to a certain extent - to adjust the inside temperature. It is a substitute for - but at times only an addition to - ventilation.

- **Drip irrigation (micro-irrigation)**

This is the most widely used system in greenhouses owing to several well known advantages: the possibility of automation and fertirrigation, continuity of water supply, efficiency, low level of evaporation, etc.
Among the advantages it offers, two are of paramount importance but are effective only on well drained soil:

(*) Feyen J., Leliaert J. (1980) - "Traité pratique de l'irrigation sous pression" A.G.C.D., Place du Champ de Mars, 5, 1050 Bruxelles.

a. efficiency : in many situations water shortage is a real problem and automation, which allows small quantities of water to flow 24 hours a day without discontinuity, is the only way to overcome it;

b. utilization of saline water : this can be done provided that the soil drainage is good enough to allow frequent irrigations - they keep the osmotic pressure of the soil solution low and uniform - and water can be supplied slightly in excess : in this way the salts are leached away.

Many drip irrigation systems (one of them is called "trickle-irrigation") are being marketed under their specific trade marks (Netafim, Biwall, Key-clip, Vortex, Viaflo, RIS, Naan, etc.). Describing all the systems and choosing the one most suitable for use under particular conditions go beyond the scope of the present work and specialized publications should be consulted.

However, a few brief considerations may help to use and manage these systems properly:

- One of the most common problems in drip irrigation is **clogging of the drippers**, owing to the narrow micro pores through which the water must pass. Susceptibility to clogging is closely linked to the irrigation system, but adequate filters are always an absolute necessity. A 120 to 150-mesh filter is usually sufficient for underground water but, if water comes from open basins, an additional sand filter is necessary.

  The use of self-cleaning or cheap replaceable drippers is a good way to prevent the system from becoming inoperative by clogging when the filter is not fully efficient.

  If water with a high soluble salt content is used, e.g. bicarbonates, clogging may occur owing to salt precipitation along the system, mainly at the openings of the drippers. In these conditions it is recommended to wash the irrigation system through with an acid solution from time to time in order to dissolve solid residues.

- The **distance between drippers** depends mainly on soil texture. The lighter the soil, the shorter should be the interval between drippers along the tube. 40 to 50 cm is the most common distance for greenhouse vegetable irrigation. This ensures a continuous strip of wet soil along the row unless the soil is too coarse. The wide pores of sandy soils hamper the lateral movement of water, which means that the interval between drippers is to be reduced.

- A good drip irrigation system should **distribute water evenly** along the row. This means that the first plants must not receive greater amounts of water than those at the end of the line.

- The system should also be **easy to assemble** and to remove at the end of the cropping cycle for soil cultivation. In some cases, the tubes are difficult to roll and the drippers get damaged very easily when the system is moved about in the greenhouse.

  Drip (and even trickle) irrigation systems are growing relatively **cheaper and cheaper**, and so are becoming one of the most profitable investments in protected cultivation and their use is spreading everywhere. However, in certain countries or particular regions, users may face difficulties in getting imported materials or other socio-economic restrictions. In these circumstances, less ideal but cheaper systems are recommended because they are nevertheless a long way ahead of furrow irrigation. As these systems are a real alternative in many situations they are described below:

Perforated-hose irrigation

The perforated hose is a 0.15 mm thick black PE hose-pipe, 6 cm wide when flat (i.e. 38 mm in diameter when inflated). Often, very thin laser-drilled holes are provided every 20 cm (4 holes of 0.8 mm in diameter, two of them are 5 mm above the fold and the other two, 5 mm under).

Smooth operation requires an optimum water pressure of 25 to 100 g/cm², which corresponds to a container (preferably a barrel in the greenhouse) filled with water, raised 25 to 100 cm from ground level. Any horticulturist can arrange this in his greenhouse. The flow per metre of hose depends on the pressure at the perforations. The following table shows the flow of 4 hoses per greenhouse depending on their length and on the working pressure.

Table 17 Flow in litres per second of 4 PE film perforated hoses running simultaneously in a greenhouse, depending on the length of the greenhouse and on the working pressure (in m of height of water). (From TABRESSE et al.)

Length of the greenhouse (m)	Working pressure (in m. of height of water)	
	0.3 m	0.4 m
25	1.9	2.1
30	2.2	2.6
40	3.0	3.5
50	3.7	4.3

Water is properly distributed throughout the greenhouse so long as:

- the hose does not run up a slope of more than 1%;
- the hose is not laid on a counterslope;
- the greenhouse is not more than 40 m long.

The discharge of the jets depends only on the pressure at the perforations: water is projected to 60 cm from the hose under a pressure of 0.3 m of water, 90 cm under 0.5 m of water and 110 cm under 0.7 m of water.

Perforated hoses are easy to install : for example, a rigid PVC pipe fitted with T-joints feeds the hoses laid on the ground at right-angles to the main. The hoses are linked directly to the main by collars or through a piece of rubber. Obviously, a hose is sufficient for 2 rows of plants.

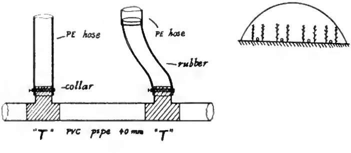

Fig. 85: Branching of perforated hoses from the main and their distribution through a greenhouse. (From TABRESSE et al.)

In this way, several paths of the greenhouse are left in a dry condition and access to plants for maintenance and harvesting is ensured.

5.3.2 PROBLEMS ASSOCIATED WITH IRRIGATION

A. Soil salinity control depends on the quality of the water, the management of the irrigation system and the drainage of the soil. To allow the use of rather saline water it is necessary to maintain a high moisture level in the soil so that the osmotic pressure of the soil solution remains low. Any excess of salt due to water evaporation and to water absorption by plants, which would increase soil salinity, must be washed down into the ground. For this purpose, irrigation water should be applied in excess of plant needs to fulfil leaching requirements.

Regarding soil salinity, fertirrigation is preferred to the use of solid fertilizers. If low-concentration nutrient solutions are used regularly, soil conductivity does not increase so much as when rather large amounts of solid fertilizers are applied at once.

Increased soil salinity makes it more difficult for roots to extract water from the soil solution, especially in hot and dry conditions, and may result in toxic concentrations of ions in plants.

Table 18 shows the tolerance of vegetable crops to soil salinity, and Fig. 86 suggests quality standards for irrigation water.

Table 18 Relative salt tolerance of some vegetables

Vegetables ranked in order of decreasing salt tolerance	EC_e (*) (mmho/cm at 25°C) at which potential yields are :		
	100%	90%	75%
tomato	2.5	3.5	5.0
muskmelon	2.2	3.6	5.7
cucumber	2.5	3.3	4.4
sweet pepper	1.5	2.2	3.3
lettuce	1.3	2.1	3.2
greenbeans	1.0	1.5	2.3

(*) EC_e - electrical conductivity of saturated soil extract.
One mmho/cm is equivalent, on the average, to 640 ppm of salt.

The diagram (Fig. 86) classifies irrigation water according to the electrical conductivity in micromhos per centimeter (salinity hazard) and to the sodium absorption ratio (sodium hazard) calculated as

$$\text{S.A.R.} = \text{Na}^{+} \Bigg/ \sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}} \qquad 5.3.2.\text{-}(1)$$

all ions expressed in milliequivalents per liter.

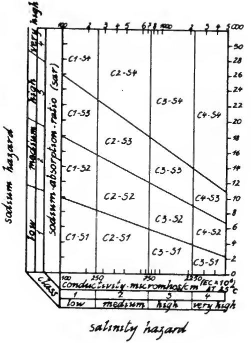

Fig. 86: Quality standards for irrigation water.
(RICHARDS L.A. et al. (1954) : "Diagnosis and Improvement of Saline and Alkali Soils - USDA Handbook N°60)

Conductivity :

Low-salinity water (C_1) - can be used for irrigation with most crops in most conditions.

Medium-salinity water (C_2) - can be used if a moderate amount of leaching occurs.

High-salinity water (C_3) - can not be used in soils with restricted drainage. Special management for salinity control may be required.

Very high salinity water (C_4) - is not suitable for irrigation under ordinary conditions, but may be used occasionally under special circumstances.

Sodium :

Low sodium water (S_1) - can be used for irrigation in almost all conditions.

Medium sodium water (S_2) - will present an appreciable sodium hazard in certain conditions.

High sodium water (S_3) - may produce harmful levels of exchangeable sodium in most soils and will require special soil management.

Very high sodium water (S_4) - is generally unsatisfactory for irrigation purposes except at low (C_1) and perhaps medium salinity (C_2) unless calcium is added to the soil.

Salinity problems in protected cultivation may be very serious. Since crop production is directly dependent on irrigation and the leaching action of rainfall is absent, water management to control salinity and exchangeable sodium in the soil is very difficult.

B. The use of plastic film to protect the soil reduces the extent of ground evaporation in the total phenomenon of evapotranspiration (E.T.) which includes the "loss of water" by the soil and by the plants. When crops do not cover the ground (e.g. tomatoes, eggplants, peppers, etc., immediately after they have been planted), mulching helps cut down E.T. since at that stage evaporation from the ground represents an important part of the total phenomenon. Later on, when the crops have developed fully and the ground is almost entirely covered, evaporation represents a very small part and E.T. is hardly affected by mulch.

Moreover, mulching prevents salt accumulation at the soil surface : the soil conductivity is reduced and moderately saline water can be used for drip irrigation.

C. Irrigation requirements can be determined in two ways:

- **measuring the soil moisture** gives an idea of the moisture available to plants. It is empiric (the grower "feels" the soil) or scientific (tensiometers or electrodes).
- referring to meteorological data makes it possible to **calculate the water availability**. This involves the calculation of consumptive use - the water lost by evaporation and transpiration - and is probably the best index.

Although it varies with a great number of factors, in protected cultivation, global radiation is the most important element and, therefore, several formulae are based on it.

In France, studies carried out by INRA and in particular by O. de VILLELE, have shown the following formula to be satisfactory:

$$PET = 0.67\ Rg/60 - 0.2 \qquad 5.3.2.-(2)$$

in which : PET = potential evapotranspiration (mm/day)
Rg = global radiation (in a greenhouse) expressed in cal/cm²
60 = latent heat of vaporization of water (cal).

However, in the Mediterranean zone, this formula needs modification at national or even regional level. For example, it is felt by VERLODT and

VANDEVELDE to overestimate the water requirement in Tunisia (as a result of global radiation).

As actual evapotranspiration (AET) is only a part of the potential evapotranspiration (PET), depending on the crop and on its stage of development, a correction factor (K) must be used:

$$AET = K. \ PET \qquad 5.3.2.-(3)$$

From Tables 19 and 20 it is possible to calculate the daily water requirement, multiplying K by the correct value of PET.

Table 19 Some examples of K values

Crops	K
tomato	0.7 - 1.2
muskmelon	0.6 - 1.0
lettuce	0.9 - 1.2
carnation	0.6 - 1.2
rose	0.8 - 1.0

Table 20 Potential evapotranspiration (PET) inside a plastic greenhouse at Sousse (35° 50' Lat. N), calculated according to De Villele's formula

Month	Evapotranspiration (mm/day) for the sky being :			
	clear	slightly cloudy	cloudy	covered
January	2.3	1.9	1.3	0.8
February	3.0	2.5	1.8	1.1
March	4.0	3.3	2.3	1.5
April	4.9	4.2	3.0	1.9
May	5.6	4.8	3.4	2.2
June	5.9	5.0	3.5	2.3
July	5.8	5.0	3.5	2.3
August	5.2	4.5	3.1	2.0
September	4.3	3.7	2.6	1.7
October	3.3	2.8	2.0	1.2
November	2.4	2.0	1.4	0.9
December	2.0	1.7	1.2	0.7

D. The irrigation timing mainly depends on the irrigation system and on the water retention capacity of the soil. The amount of water to supply per application is given by the number of days between any 2 irrigations times the daily requirement. Frequent but moderate irrigations favour the development of a small and shallow system, with a high capacity for water and nutrient absorption. However, crops become very sensitive to drought once the volume of exploited soil is reduced and the reserve of water is meagre. It should be kept in mind that the dependence of plants on an irrigation system increases with the accuracy and efficiency of the latter.

Furthermore, the dangers for plants exposed to a succession of dry and wet periods (concerning their water supply) cannot be underestimated: water should be supplied frequently in small doses.

5.4 PEST AND DISEASE CONTROL

Much could be written about plant protection, but in the present circumstances only the most important aspects related to protected cultivation will be dealt with, particularly the influence of environment on disease control.

5.4.1 SOIL DISEASES

Soil diseases constitute a major problem and one that affects many crops (e.g. Fusarium spp. damaging the carnation and the muskmelon) and arises from various causes, e.g.

1. the lack of sufficient profitable crops that excludes crop rotation; monoculture is frequent;
2. the intensive cropping calendar that results in ground occupation without discontinuity;
3. soil moisture levels and soil temperatures that favour the development of fungi and nematodes.

Infected soil is an important limitation for many crops.

A. Soil sterilization is the most common way to solve soil disease problems. Complete sterilization is by no means the aim of the process, which must be strictly limited to the destruction of pathogenic micro-organisms, and to the safeguard of useful bacteria such as the ammonifying and nitrifying bacteria.

However a sterilized soil is not safe from new infections. It undergoes contamination from the air, from deeper layers of soil, from plants, from seeds,... and these new infections are worse because the soil microflora is no longer in equilibrium and, therefore, pathogens are free to develop faster.

Steam sterilization is the traditional system. It is effective but expensive, and requires boilers hardly ever available in Mediterranean greenhouses. **Fumigants** are therefore preferred. Many formulations are available : in solid or fluid form, more or less toxic, and having different spectra regarding pathogen control. The substances should be chosen to serve each specific situation. Table 21 summarizes the efficiency of several active substances. Soil fumigants are not completely effective; the diseases are seldom fully controlled. Their efficiency depends on the soil temperature, texture and water content and on the method of application. Covering the soil with a PE film after treatment improves penetration and reduces gas losses.

Methyl bromide is one of the most effective products listed in Table 21 but it is difficult and dangerous to apply owing to its high toxicity and because it leaves bromide residues in the soil.

Table 21 Efficiency and degree of penetration of several soil fumigants (- null or unknown effect; relative efficiency from x to xxx)

Active substance	Herbicide	Fungicide	Nematocide	Penetration
Dichloropropene + dichloroethane	-	-	xxx	x
Chloropicrin	x	xxx	xxx	xxx
Methyl bromide	xx	xxx	xxx	xx
Formol	x	xxx	x	-
Sodium dithiocarbamate	x	xxx	xx	-
Dazomet	xx	xx	x	x

B. Solar disinfection of the soil, "solarization", is an alternative method, active against various pests, weeds and diseases, which does not involve the use of chemicals, and uses solar energy to increase the temperature of the soil by covering it with a transparent plastic film during the warmest period of the year. This temperature rise results from the high solar radiation transmissivity of the film and the reduction of convection and evaporation losses. It destroys quite a number of parasites and causes biological, physical and chemical changes in the soil, which turns this technique into an integrated control method with a wide sprectrum.

It is relatively cheap, and is harmless to man or other living organisms.

Time of year - Long clear days, high temperatures, no wind. In the Mediterranean countries these conditions occur mainly in summertime.

Materials - Transparent polyethylene film 0.025 to 0.050 mm. When solarization is combined with subsequent mulched cultivation, the film thickness can be increased for longer use. In the estimate of the cost price given below, the film is only used once, for solarization and not for mulching.

Soil preparation - Disking and rototilling are useful to get a smooth and even surface that allows water penetration. Soil must receive a good irrigation before being covered (completely or partially) by the film. A partial covering considerably reduces the efficiency of the solarization. The edges of the film must be buried in the soil.

Duration of the treatment - Four to six weeks.

Effects - The highest temperatures occur in completely closed and mulched greenhouses. In Murcia, the soil temperature in a closed unmulched greenhouse is similar to that under mulching in open air. In general the soil temperatures range from 35 to 60°C in the upper 40-cm profile.

This method has proved effective against a wide range of pathogens, such as Verticillium dahliae, Rhizoctonia solani, Meloidogyne spp. etc. and against various insects and weeds.

Table 22 Costs of different soil sterilization treatments in Murcia (Spain) in 1985.

Method	Pesetas/m²	Relative cost
Solarization (0.050-mm film, hand covering)	18.40	105
" (" " " , machine covering)	17.00	97
" (0.025-mm " , hand covering)	11.65	66
" (" " " , machine covering)	10.25	58
Metham - Sodium	17.50	100
Methyl bromide	50.45	288

C. Alternative methods of preventing soil infection are :

- **artificial substrates:** many systems are used : rockwool, Nutrient Film (N.F.T.), peat bags, etc ... They imply the use of high technology and as a result are not very widespread in some regions of the Mediterranean area.
- **resistant cultivars:** these are already available for some crops with respect to major soil diseases, e.g. tomato cvs. resistant to Fusarium, Verticillium and nematodes. Progress in plant breeding may increase their number in the near future.
- **greenhouse moving:** it is an efficient system when there is no land shortage and greenhouses are easy to assemble elsewhere. Under some specific conditions it is better to move the greenhouse than to carry out an expensive process of soil disinfection. Carnation growers may follow this system.
- **grafting:** when no resistant cultivars are available, some crops can be grafted on a resistant rootstock, e.g. Benincasa may be used as a rootstock for muskmelon in soils infected with Fusarium.

As a rule, the various cultivars of tomato offer a sufficient affinity with K.V.F.N. hybrids created from various Lycopersicum and fairly resistant to corky root (K), to Verticillium (V), to Fusarium (F) and to nematodes (N).

The eggplant may be grafted on the same K.V.F.N. rootstock or on some varieties of resistant tomatoes (Verticillium) or else on some other Solanum species such as S. torvum, S. integrifolium or even S. melongena to gain resistance to Pseudomonas solanacearum.

5.4.2 PLANT FUNGAL DISEASES

Fungi affecting protected crops pose a constant threat because the greenhouse environment with high humidity and warm temperatures provides them with adequate growing conditions.

Most diseases of the aerial parts of plants can be controlled by fungicides, and more efficient substances with increasing specificity are appearing every year.

However, they present some important negative aspects:

1. fungal resistance to systemic fungicides, e.g. Botrytis versus benomyl;
2. increasing price of fungicides and cost of application;
3. excessively high residues in plants when repeated treatments are necessary.

Therefore, it is necessary to complement them by other means of control so that they become more efficient and can be used sparingly.

The first and most important point is to avoid giving diseases adequate environmental conditions for growth, by using resistant cultivars and by modifying the climate so that it becomes unfavourable to them. This is often not very easy to achieve because the optimum environmental conditions for the fungus vary considerably. Some fungi need moisture films in order to germinate their spores (mildew and anthracnose); others only high humidity (Cladosporium or rust); but powdery mildew develops quite well in hot and rather dry climates. Stemphylium, Septoria and Alternaria can develop at a relatively low temperature. If one adds the different crop susceptibilities, we arrive at a great number of pathogenic situations.

An unheated Mediterranean greenhouse, combining high night humidity with fairly high day temperatures provides an adequate environment for fungal development. **Reduction of air humidity** is the easiest way to counteract this situation. During the night the reduction is difficult to obtain without heating, but in certain cases some ventilation may reduce the amount of condensation. The plants must become dry early in the morning to avoid the combination of moisture with increased temmperature that favours fast fungal development; when the greenhouses are well ventilated, Botrytis and Phytophthora diseases are somewhat reduced.

Reduction of air humidity may be achieved in various ways:

1. to mulch the soil with plastic and to practice drip irrigation help reduce evaporation;

2. to strip plants of their lower leaves, to widen the spaces between plants and to improve the design of the greenhouses ameliorate air circulation;

3. to provide double-wall covering or to ventilate in the evening in order to lower the absolute humidity of the air: both reduce condensation.

However, provision must be made to avoid dramatic falls in air humidity during daytime with subsequent closure of stomates and wilting of plants. Ventilation is helpful even near the saturation point, since air movement over the leaves removes surface moisture and can be effective in avoiding the germination of spores requiring liquid water.

Care should also be taken:

1. to remove **weeds**, since they obstruct ventilation and increase humidity at ground level;

2. to remove **plant residues** such as pruned leaves that are often a contamination centre;

3. to avoid **wounding** plants, since wounds offer the easiest way of penetration for some fungi.

- Fungicides can be roughly divided into **contact** and **systemic** types.

The **first group** protects the plant surface, preventing spores from germinating. They can be washed away by rain and do not protect the leaves or stems that have not been sprayed. Rain is not a problem inside a greenhouse but as plants grow very fast they must be sprayed regularly to keep new shoots continuously protected.

The new generation of **systematic fungicides** is free from these inconveniences. They circulate in the sap, protecting the whole plant from the inside and can destroy fungi even after infection. However, resistance is stronger than with the contact ones. Systemic fungicides are applied less frequently and sometimes only after the first symptoms have appeared. As a result, they are cheaper and less labour-demanding.

Most commercial formulations combine systemic with contact fungicides to widen the spectrum and decrease the resistance problems.

5.4.3 VIRUS DISEASES

These diseases are systemic; the infection never leaves the plants.

Virus diseases are **transmitted** in various ways :

1. mechanically : pruning, hand contact, etc. with very stable viruses such as the tobacco mosaic;
2. by insects : this is the most frequent way;
3. by seeds : quite exceptional, e.g. lettuce and tobacco mosaic;
4. by nematodes in the soil : e.g. tomato black-ring virus and tobacco mosaic.

Viruses do not usually kill plants but reduce their vigour and productivity. The **symptoms** are very complex and difficult to identify because the same virus may show different aspects depending on the host. The common symptoms are **mosaic, yellowing and leaf rolling.**

Up to now, as hardly any remedy can relieve a plant of a virus after it has been infected, all the **treatments are preventive**, e.g. the use of tested mother plants for vegetative propagation; the reduction of contamination by removing infected plants and controlling aphids, and in some specific situations, the use of netted-window aphid-proof greenhouses.

Inoculating plants with weaker races of viruses with a view to inducing immunity is a realistic course against some very dangerous viruses **(premunition)**. This system used to be applied to protect tomatoes from the tobacco mosaic virus (TMV) before resistant cultivars became available.

5.4.4 BACTERIAL DISEASES

The most important bacteria affecting plants are: Corynebacterium, Pseudomonas, Erwinia, Xanthomonas and Agrobacterium. Their physiological behaviour in plants is much the same as that of fungi but they are less affected by the environment.

As there are no efficient bactericides - antibiotics are not used on food crops in the greenhouse and copper is not always effective - preventive action is very important. Some bacteria are transmitted by seeds (Corynebacterium), others may remain in the soil. Most of them are very sensitive to heat and can be destroyed at rather low temperatures (60°C), soil disinfection by steam being very effective.

Bacteria-free seeds (i.e. produced in healthy soils and tested by fluorescence) will most probably afford a minimum guarantee in the early stage of cultivation. Later on, all the techniques that contribute to make up a resistant foliage should be resorted to: water stress, copper treatments, etc. should be avoided.

5.4.5 MISCELLANEOUS

Pests are of minor importance in protected cultivation because insecticides have become fairly efficient.

In some circumstances, however, **insects** may remain difficult to control either because they have developed a certain resistance to insecticides or because of the impossibility of applying the best treatment at the most appropriate time because of toxicity (e.g. during harvesting). The only way left to control them is to use the greenhouse as a closed space, putting up insect-proof nets on the windows. This is a very efficient and cheap means to control whitefly but it may create ventilation problems as the nets considerably decrease air circulation within the house. Unfortunately, the whitefly is a plague mainly related to the warmer regions where the problems of high temperatures inside greenhouses are most frequent.

Resistant cultivars are probably the solution to control diseases. Resistance seems to be a more profitable criterion of selection than absolute potential yield. Although there is still a long and difficult way to go before totally disease-free plants are produced, the market already offers vegetables and flowers which show very interesting resistances. Most of them are resistant to viruses, nematodes and fungi including several soil-borne ones such as Fusarium spp and Verticillium spp.

Pesticides are applied in much the same way as in the open:

- **spraying** is widely used but requires special equipment;
- **"fog-system"** is based on the principle of conveying pesticides in the form of a mist. A portable machine is used to produce a cloud of micro-droplets with high penetration power. This system is specially recommended for application of insecticides in closed spaces - though it also gives good results for the application of fungicides. It uses ultra-low-volume concentrations, thereby avoiding the need for large water tanks and making treatments very easy and fast.
- **solid insecticides** can be incorporated into the soil. They are absorbed by the roots and offer long-lasting protection to the whole plant. The best known is Aldicarb, mainly used for ornamentals. It controls mites, aphids and scale insects for at least 3 months after being applied to the soil. Owing to toxicity problems, they cannot be used for edible herbaceous crops.

The cost of plant protection in protected cultivation represents a relatively low percentage of the production cost. But owing to the high value of the crops involved and the necessity for perfect sanitary control, the absolute value is very high compared to plant protection in the open.

5.4.6 BIOLOGICAL CONTROL

It should be emphasized that "biological" control should be promoted whenever possible. With this method, pest control is carried out by means of specific predators which act as parasites of the pests to combat. Biological control is often part of a global approach called "integrated pest management" where the use of low-toxicity products is advocated in order to reduce pest residues on the commidities and to protect the environment.

When a grower faces a serious infection or a massive attack by a pathogen, he would be well advised to resort to chemical treatments before he introduces specific "auxiliaries".

Biological control is expanding rapidly in the northern regions of the Mediterranean zone (France, Italy,...) where the infrastructure needed to breed those specific auxiliaries has been developed, for instance:

- Phytoseilus persimilis, a spider that preys on Tetranychus urticae;
- Encarsia formosa, a hymenopteron that destroys the white fly Trialeurodes vaporariorum (Encarsia does not attack the other "white fly", Bemisia tabaci);
- Aphidium matricariae, that keeps down colonies of Myzus persicae (aphids).

The biological control of other aphids by specific predators such as some lady-birds or of various nematodes by fungi that feed on nematodes (Arthrobotrys irregularis and others) is about to be commercialized in Europe.

Similarly, it can be added that some virus diseases can be controlled not only by premunition (as already stated before) but also by the use of antagonistic microbes like Trichoderma viridis, etc.

It has been reported that certain soils have a slow-down effect on the development of some specific fungi (Rhizoctonia solani, Fusarium oxysporum, Pythium spp.), when mixed in a 5 to 10% ratio with the substrates used for greenhouse cultivation. This technique is being further investigated, e.g., at INRA (Dijon, France) in relation to carnation bench growing systems in southern France.

5.5 **WEED CONTROL**

Weeds can be controlled more easily in protected cultivation than in outdoor cultivation, especially when particular techniques such as mulching and drip irrigation are applied. In addition, the disinfection of the soil by means of the fairly efficacious products currently available commercially helps keep down weeds. The type of soil plays an important role : weeds develop less in sandy or desert soils with a low organic matter content than in heavy and rich ones.

Soils infested with perennial weeds such as wood sorrel (Oxalis sp), Bermuda grass (Cynodon dactylon) and nut grass (Cyperus rotundus) should be carefully disinfected before greenhouses are erected on them. **Glyphosate** gives satisfactory results when applied during the early flowering stage of these weeds and provided it is accompanied by abundant irrigation to assure good translocation of this systemic herbicide.

Nurseries pose few problems as planting is mainly done in blocks or pots, which means that the substrates are generally sterilised. North African countries, however, continue to transplant solanaceous crops bare rooted and, therefore, nurseries have to be treated.

For the **tomato**, the results show that **metribuzin** (250 g/ha) is more selective when incorporated before sowing than before emergence. The addition of **diphenamid** (3000 g/ha) or **butralin** (1500 g/ha) to 150-200 g/ha of **metribuzin** widens the spectrum of activities and ameliorates selectivity.

For **pepper** plants, pre-emergence treatments with diphenamid (5000 g/ha), **butralin** (2500 g/ha) or **diphenamid** (2500 g/ha) + **butralin** (1250 g/ha) prove efficient.

Chemical weed control in a **greenhouse tomato** crop can be carried out successfully with a mixture of **metribuzin** (350 g - 400 g/ha) and **diphenamid** (3000 g/ha) or of **metribuzin** (350 g - 400 g/ha) + **butralin** (1500 g/ha) without any risk to the crop. The combination of a pre-planting treatment of **metribuzin** (500 g/ha) or of **metribuzin** (350 g/ha) + alachlor (1000 g/ha) or of **metribuzin** (350 g/ha) + **diphenamid** (3000 g/ha) with a post-planting treatment of **metribuzin** (350-400 g/ha) offers a longer protection.

Under small tunnels similar treatments can be applied.

If a transparent **mulch film** is used, a more intense weed activity is observed due to the higher temperatures under the mulch. In the case of direct seeding, the herbicides spread before the installation of the mulch have no selective action on the crop. The best results are obtained with **metribuzin** (400-500 g/ha), **metribuzin** (300 g/ha) + **diphenamid** (3000 g/ha) and **metribuzin** (300 g/ha) + **butralin** (1500 g/ha) applied just before mulching. Higher doses of butralin are toxic.

Weeds in a **muskmelon** crop can be controlled successfully with **dipropretyn** (2500-3500 g/ha). However, significantly better results are achieved with the following mixtures:

chlorthal-dimethyl + **dipropretyn** (3750 g + 1250 g/ha
chlorthal-dimethyl + **naphtalam** (3750 g + 2000 g/ha)
naphtalam + dipropretyn (2500 g + 1250 g/ha)
chlorthal-dimethyl + **assulam Na** (3750-5000 g + 2500 g/ha)
dipropretyn + **assulam Na** (1250 g + 2000 g/ha)
the addition of **assulam-Na** is only necessary if compositae or Urtica repens are present.

If a transparent **mulch film** is used in combination with a greenhouse or a small tunnel, the rates of application should be reduced as a result of the higher activity of the herbicides and of their more aggressive effects on crops.

Weed control on a **pepper crop** is very specialized because of the low growth rate of this vegetable during the first months and the long growing cycle of the varieties currently grown. This involves the use of persistant herbicides. Mixtures of **alachlor** (1500 g/ha) with **diphenamid** (3000 g/ha), with **butralin** (2000 g/ha) or with **pendimethalin** (1000 g/ha) are very effective if used as a **pre-planting** treatment. The mixture **diphenamid** (3000 g/ha) + **butralin** (2000 g/ha) is also promising.

The use of **diphenamid** as a **post-planting** treatment after hoeing can extend the protection against weeds until the harvesting period.

5.6 MECHANIZATION

Wise planning of a horticultural enterprise, together with the judicious utilization of tools, lighten labour and turn horticulture into a more profitable business.

5.6.1 GENERAL ORGANIZATION OF THE ENTERPRISE

The infrastructure of every horticultural enterprise involving protected cultivation must be designed so that:

- the greenhouses are of easy access and the produce can be carried out rapidly and without obstruction. One must remember that the horticulturist is above all a "carrier". Huge greenhouses must be divided by a central path that should preferably be of concrete. The doors must be wide and equipped with simple closing devices that can be operated both from the outside and the inside.

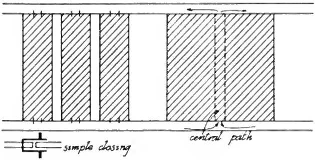

Fig. 87: General disposition of greenhouses

- a **warehouse** is provided to stock fertilizers, machinery and plant protection products;
- a **shed** allows the handling and packing of the produce when these operations are carried out by the grower;
- **another shed** is reserved for the plant protection equipment, irrigation apparatus and fertilizer distributors;
- the enterprise is **connected** to the elctricity grid and to the telephone network.

5.6.2 MECHANIZATION OF SOIL PREPARATION

Formerly, everything used to be performed manually and sometimes draught animals were used to alleviate the work. Nowadays, a great variety of small machines are commonly used, designed to fit the special dimensions of the plots inside the greenhouses. For instance, motor scufflers, motor hoes, and above all, the two-wheeled tractors, whose power ranges between 2 and 12 HP, specially designed to be equipped with different tools such as ploughs and rotary cultivators or to haul trailers. 8 to 20-horse powered microtractors are increasingly used. These articulated machines with four-wheel steering have a very short turning radius.

5.6.3 IRRIGATION AND FERTILIZATION

The minimum equipment required is a pump to ensure sufficient pressure to the filtering system and, when fertirrigation is applied, a tank or a system with injectors.

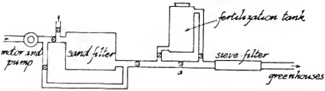

Fig. 88: Diagram of a simple fertilizer injection system (fertirrigation)

- Electric motors are preferred, but diesel or petrol engines can also be used.

- Sand-filters eliminate the coarser particles. Cleaning is done by circulating water in the reverse direction. Sieve-filters are cleaned with a pressure water jet.

- The simplest fertilization system is made up of a tank as shown in the diagram (Fig. 88). By modifying the rate of flow at a it is possible to regulate the flow of water through the fertilizer container. This system lacks accuracy but has the merit of being simple. More important enterprises can also use hydraulic dosers, which are more precise, or programmed electric injectors.

Water can be supplied in many ways, but Mediterranean climatic conditions demand localized irrigation, and this is often achieved by the drip irrigation system. At the nozzles, a very thin capillary pipe or a thread or some other device causes the pressure to fall and water to be expelled in drops instead of in the form of a regular jet. There is a water outlet near each plant. Microjets are preferred when plant density is high or when the soil needs leaching.

There exist other systems like the "oozing sheaths" or "water covers" used to irrigate pots, but these are particular solutions to specific cases.

5.6.4 CROP PROTECTION

Since most chemical products are formulated for spray application, the following lines are mainly devoted to spraying equipment. All of them consist of a reservoir to contain the mixture, a hand- or motor-driven pump to provide the necessary pressure and a nozzle to achieve droplet formation.

Mobile devices

The most commonly used device is the portable sprayer, often made of plastics and, therefore, lighter and rust-proof. The pump is manually activated by a lever.

There are also motor sprayers, but these are heavier and almost always mounted on wheels; they contain 100 litres.

Finally, there are also sprayers with a capacity of 400-500 litres, using the power of a minitractor. Portable motor dusters are particularly useful.

Permanent systems

Fixed fittings are particularly recommended for larger enterprises. Tanks and pumps are installed to supply crop protection chemicals throughout the greenhouses via a permanent system of pipelines. These systems save labour, since several parts of the greenhouse can easily be reached by connecting the spraying hose to one of the different taps distributed throughout the greenhouse.

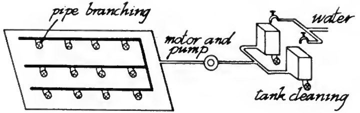

Fig. 89: Diagram of a permanent installation to supply crop protection chemicals throughout the greenhouses

5.6.5 OTHER OPERATIONS

In most cases, sowing and planting are manual operations, assuming that the areas are not too large, otherwise these operations can be mechanized: precision seeder, planting machine, transplanter, bulb and tuber planter, digger, lifter, harvester, etc.

Particular implements have also been devised to facilitate the work of ornamental plant cultivation, e.g. appliances to prepare (mix, grind...) substrates and also to fill the pots.

5.6.6 PACKING AND TRANSPORT

Many types of appliances exist on the market to perform grading and packing mechanically. Transportation equipment has also to be selected according to the size of the enterprise. This may range from a simple barrow or a tractor-hauled trailer up to rail conveyance - even by overhead monorails.

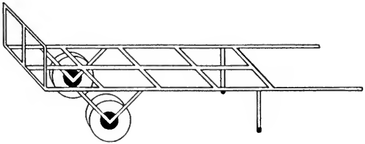

Fig. 90: Barrow for the transportation of boxes in the greenhouse

CHAPTER 6

CROP PRODUCTION

6.1 GENERAL ASPECTS

6.1.1 USE OF GREENHOUSES

The use of greenhouses and tunnels in the Mediterranean regions varies greatly from country to country and no description can be given that could cover the Mediterranean area as a whole.

This phenomenon of local variation is based on various reasons :

- **the characteristics of the local climate** : the type of plants grown must logically fit the climatic characteristics observed. For example, a cold winter climate with little sun normally leads to the protected cultivation of lettuce, whereas a region characterized by high winter insolation and, as a result, mild to high temperatures, fits the needs of plants such as tomatoes, which are in fact more demanding;

  similarly, the characteristics of the summer climate also influence the choice of crop. It may even prove wise - in certain latitudes - not to use greenhouses during the warmest months or at least to use short duration films stretched over the structure from October to May (see § 6.1.3);

- **the local economic conditions** (depending to a certain extent on the climate): some countries endeavour to produce heat and light-requiring plants such as tomatoes in winter even though plants such as these can hardly be grown under cold shelters since the night temperature approaches or is even below their physiological threshold. E.E.C. looks attractive enough as a potential market for those countries to choose this market instead of a local one;

- **the sociological factors** appropriate to the country : some countries are practically deprived of potential domestic markets for crops that are more easily grown under cold (low) shelters in winter due to their lower degree of heat requirement (lettuce, celery).

Though this may seem a rather simplistic assertion, it may be said that some economic requirements distort the normal distribution of production based on climatic assets quite significantly. Although the local market may in some instances be in a position to absorb large quantities of vegetables whose winter production is subject to efficient protection, the growers or their advisers think it best to turn to export, a source of strong currencies, rather than to the production of vegetables likely to stock and diversify the local market.

6.1.2 **CROPS SUITABLE FOR PROTECTED CULTIVATION**

The range of crops suitable for greenhouse growing in the Mediterranean area is comparatively small. Tomato is second to none; it remains the most profitable vegetable the world over. Sweet pepper, melon and probably squash are to be found well behind. Eggplant, cucumber and water melon come further down the list. Lastly, and as a curiosity if one considers the Mediterranean region as a whole, strawberry, lettuce and bean can be cited. It must not be forgotten that some of these vegetables are easily grown under low tunnels during several of the winter months.

It is therefore **high time that** the **Mediterranean region diversified** its **production.** First of all, this would obviously help local consumers with their diets, and furthermore, the investments made would return better profit. However, such diversification looks neither simple nor obvious: indeed there are few vegetables in daily consumption apart from those listed above that require more favourable climatic conditions than the winter ones observed in the open throughout the Mediterranean region. Besides, new diet patterns are slow to be accepted and need the backing of vast publicity campaigns.

Another way towards diversification might be the introduction of various **ornamental** plants within the cultural structure. Of course, the mediterranean market does not look attractive as a result of the numerous decorative plants that grow naturally in the particular climate of the region. However, two new options may be seen:

- the production of exportable "finished" plants;
- the cultivation under a milder climate of plants or parts of plants destined to be (re)exported to colder regions as cuttings, rooted or non-rooted plantlets, etc.

This explains why the cultivation of various ornamental plants is mentioned in the following paragraphs though these plants are not frequently grown in greenhouses in the Mediterranean region during winter time.

Yet another possibility not to be neglected is the winter production of **fruits** normally produced during the summer season (grape) or - provided that economic circumstances allow it - the all-the-year-round production of tropical or equatorial fruit not imported in large quantities into the Mediterranean region and which are therefore destined for local consumption (bananas,...).

6.1.3 CULTIVARS GROWN

In addition to species or varieties of local origin and interest, most Mediterranean countries produce under shelter cultivars that are much similar to each other and that belong to some large types or classes which could be labelled as "international" even though they are not necessarily destined to the export markets traditionally sought by the Mediterranean countries.

A census of the **most important cultivars of vegetables**, ornamental plants or fruits grown in the Mediterranean protected cultivation does not lead to the conclusion that they have been chosen only for their eco-climatological requirements and aptitudes. The true incentives for a country or a region to adopt a particular cultivar are rather to be found in its success on the export market, in its aptitude to grow and fruit in the local climate and in the local demand which may favour the external appearance of the product rather than its taste, its nutritive value or its suitability for market. These local taste criteria definitely orientate the choice in some cases.

Therefore, the final choice of one cultivar among the many "international" ones looks subjective rather than objective. Any attempt to draw a lesson from the knowledge of the characters of the cultivars most frequently grown in the various Mediterranean countries and to suggest in the present document ways to guide the growers and their advisers in their choice to improve productivity is perfect utopia.

The power of the local character (taste) becomes plain in the task that research workers have undertaken in many Mediterranean countries : they patiently endeavour to cross-breed international cultivars with varieties particularly appreciated by their fellow-countrymen who have been growing and consuming them for ages. These newly-developed cultivars escape any objective judgement, and even though some of them may be taken as real assets, it is to be feared that the superiority of many such local novelties over the international cultivars that they result from is subjective rather than objective. In other words, they tend to find favour with the growers as a result of their origin rather than because of better organoleptic, eco-climatic or economic qualities.

The same "affective need" for a local adaptation of an "international" cultivar appears also with greenhouses themselves. Indeed, the survey presented in §3.1.1 does not allow precise conclusions to be drawn as to the fundamental reasons that induce a country or a region to choose a particular type of greenhouse. In short, **tradition exerts a determining influence.**

In other words, it does not look possible in this document to establish a clear-cut and simple connection between the types of cultivars grown in any given region - or the most popular type of greenhouse - and the very characteristics of the climate of that region : the human factor, subjective by definition - in the non-pejorative acceptance of the word -, often prevails over the technical or scientific factor, which is held as objective because it allows understanding and codification.

However, since the reasons to advocate certain cultivars (or a given shelter) take so long to explain that the only way is to do it orally and for each individual case, the present chapter lists - as already done for greenhouses - **the main varieties grown in a number of Mediterranean countries.** (Such lists are not intended to establish any connection between the presence of a variety in a country and the area it occupies. This study is merely a qualitative one). When the authors decided to add this list to the other considerations put forward on the various plants grown by protected cultivation in the Mediterranean region. they regarded it as a basis for a very precise and well documented exchange of views that could ultimately lead to a rational policy of greenhouse crop production.

The existence of a "fashion" is also worth pointing out. Indeed, when a cultivar has produced good results in some countries, it progressively invades the nearby markets. Of course, the process is slow and takes time, and this is why a given cultivar which has already lost ground in or simply disappeared from its country of "origin" continues to invade other regions of the Mediterranean zone. The cycles of appearance and disappearance of cultivars in different regions follow the same curves but are spread over a period of time.

6.1.4 SOME OBSERVATIONS

A - The following pages are mainly devoted to a survey of the cultivation of **vegetables** of widespread production representing a real economic asset (tomato, pepper, etc). Less space has been allotted to description of the characteristics of vegetables which are less widely spread both inside and outside the Mediterranean region.

An attempt is made to define the chief problems of **ornamental** plant production, up to now limited to the northern part of the Mediterranean region but which could extend to other countries of the region.

Finally, a few paragraphs are devoted to **fruit** cultivation, a topic likely to be of interest to Mediterranean growers.

B. - Various problems merit particular attention in the present document:

1. **The summer use of greenhouses**; this subject has already been touched upon before. In some Mediterranean countries, crop production may be continued during the warmest months of the year, provided that ventilation is efficient and/or misting is applied, whereas in other countries, sophisticated techniques are required which do not necessarily return a profit (more "arid" zones). Each situation should be considered individually, and the transfer into the south of techniques developed in the north where they prove profitable should be avoided, e.g. long-duration plastics that in too warm regions impose:

    - either the non-use of the greenhouse in summer, which entails the progressive impairment - to no purpose - of the plastic film left on the structure;

    - or the application of advanced techniques (cooling systems) involving quite high investments which more often than not give very little if any return since competition with open air cultivation is keen during the warmest months.

Serious economic studies have to be pursued with the aim of providing the horticulturist with basic data to help him with his decisions:

- does he use one-year-duration covering sheets, the ground under the structure of his greenhouse being planted in summer without protection with end-of-cycle crops (early crops) or beginning-of-cycle ones (delayed or autumn crops) ?

- does he make investments with a view to extending spring crop cultivation into the summer period ?
- does he leave the plastic cover over the structure throughout the summer while leaving the soil bare during the warmest months ?

Each case requires a specific answer, but the problem as a whole needs full attention as it eventually conditions the regional and even the national policy of production. The subject cannot be dealt with "ex cathedra".

2. The Draft Committee has not felt the need to group all the problems related to nurseries into one special chapter. These problems are quite specific, and any systematic survey would need the back-up of numerous and varied practical examples. The reader should refrain from deducting, however, that nurseries are of minor importance in the Mediterranean region. It is precisely in this field that the traditional techniques of Mediterranean nurserymen could be improved. It has been judged preferable to summarize the particular requirements and cultural techniques for each crop, together with its period of production. The common aspects are limited to the types of substrates and to the preparation of plantlets in blocks (or in small containers) rather than in the open to avoid bare-root planting. Even though the principles are agreed, the problem needs local solutions : where to find the necessary organic material, how to make valid mixtures with locally-found constituents? Problems like these are dealt with in §5.1. On the other hand, a document has been prepared by FAO that is devoted to "soilless culture and its horticultural applications" in the Mediterranean countries. That is obviously where most of the above-mentioned subjects will be dealt with.

6.2 MAIN CROPS CULTIVATED

6.2.1 VEGETABLES

6.2.1.1 TOMATO (Lycopersicum esculentum Mill.)

A. General description

The tomato is a herbaceous plant in the early growing stage; the stem becomes somewhat lignified in the later stages of growth. Nevertheless the normal crop needs a support because of the very weak collar zone. Only plants of the dwarf or miniature type (gene "d" - dwarf - or "dm" - miniature" -) can be cultivated without staking.

A1. Root system

The young tomato plant is taprooted, but a very important ramification develops later on, so that it is very difficult to distinguish the taproot from the subsidiary roots. The rooting system of a tomato crop can go deeper than 1.25 m into the soil, but most of the roots are situated in the upper soil zone (more than 70% in the 0-20 cm zone and up to 95% in the 0-50 cm zone). Varieties of determinate growth have in general a smaller and more superficial rooting system, while direct seeded crops have a more important taproot and a deeper rooting system than transplanted ones. Light and sandy soils favour deep rooting.

A2. Growth of the plant

The tomato plant is characterized by sympodial growth. As a rule, a terminal cluster appears on the main stem after 5-8 leaves have developed (Fig. 91a). High temperatures and low light, especially when combined, delay the appearance of this first cluster. The most vigorous lateral shoot develops in the axis of the leaf that immediately precedes the cluster, to prolong the main stem (Fig. 91b). By phototropism, this shoot takes up an upward position, pushing aside the upper part of the main stem and giving the impression that the terminal cluster is positioned laterally (Fig. 91c). This axillary shoot in turn ends in a terminal cluster that appears after three leaves have developed, though sometimes after only two or even one leaf (Fig. 91d). The growth is again prolonged by the most vigorous last lateral shoot, the lower lateral ones being less vigorous.

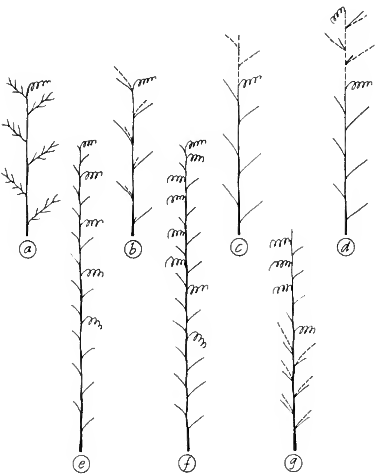

Fig. 91: Various growth types of Tomato

When the number of leaves between two successive clusters is limited to one or two, the plant is less vigorous and, under certain growing conditions, becomes exhausted and stops developing. This condition is referred to as "determinate growth" (gene "sp") as opposed to the "indeterminate growth" (gene "sp+") that characterizes the normal growth. Both types can be grown in Mediterranean greenhouses.

The indeterminate growth type is characterized by the presence of sympodes with 3 leaves and can, if growing and plant health conditions are satisfactory, be grown over a long period and produce a large number of trusses (Fig. 91e). The determinate growth type is less popular in greenhouses.

Some varieties, called "semi-determinate", develop sympodes with three or two leaves - and in rare instances one - which make them less sensitive to growth determination and suitable for greenhouse cultivation (Fig. 91f). The real determinate growth type with 1 or 2 leaves per sympode is more adapted for industrial cropping and suitable for "once over" harvesting (Fig. 91g).

Growth may be restrained or even interrupted at any stage by various factors, e.g. by low temperatures, short daylength, moisture deficiency, water stress and saline conditions. This phenomenon can appear very early (after 3 or 4 trusses), even with semi-determinate types, though under more favourable conditions these varieties can produce 10 clusters or more.

A3. Leaves

The tomato has compound leaves with an unpaired number of green leaflets whose number depends on the variety and on the level of the leaf on the plant. The shape and size, the structure, the thickness and the colour also depend on the variety. "Late" varieties have thicker and darker green foliage, but the growing conditions have an important influence.
Curling of the leaf around the leaf rachis can occur in particularly vigorous plants, especially in young plants, whilst leaf cupping deformation of the leaflets can be due to waterstress or to pruning, especially with determinate growth types.

A4. Flowers

As a rule, first-class fruits are obtained from good quality flowers developing in clusters of 5 to 12 flowers. Depending on the conditions, the number of flowers is quite small (high temperatures and low light) or quite large (low temperatures), while vigorous plants growing under humid conditions produce clusters with foliar shoots and with flowers which develop extra long sepals. At low temperatures some varieties are very susceptible to doubling, which results in ribbed or catfaced fruits.

Fruit set is largely influenced by the quantity and quality of the pollen received and by the viability of the ovules. In most cases the pollen is more sensitive to low temperatures than the ovules, while at high temperatures the viability of the ovules is also very low. Both low [<13°C] and high [>32°C] temperatures result in reduced pollen quantity. Pollen quality is reduced by low temperatures, especially during the period of microsporogenesis, when the flower is in the small button stage (about 2 weeks before blooming).

Pollen liberation is hampered by low temperatures and high relative humidity, and in this case fruit set can be improved by the use of vibration techniques. Pollen germination and fructification of the ovules is retarded by low temperatures, but not seriously affected if the pollen is of good quality.

Pollen production varies greatly in quantity and quality according to variety. In general, F1 - hybrids produce more and better quality pollen under cold conditions than traditional varieties (H63-5, H63-4, Lucy, Vemone and Luca ...), but some other hybrids such as : Elcy, Carmello, ... produce pollen of lower quantity and quality.

The flowers are yellow and composed of 6 green sepals, 6 yellow petals, 6 green stamens linked to a cone covering the pistil, so that in normal conditions the tomato is autoploid. At high temperatures the elongated pistil can pass through the stamen cone, and cross pollination is the rule.

A5. Fruit-setting

The quantity of seeds in the fruit and the size of the latter increase with the number of ovules fertilized, because the development of the fruit is linked to the production of auxin, itself a function of the quantity of seeds. If the pollen is lacking in quantity and in quality, and if the ovule viability fails to be acceptable (especially when night temperatures are low), hormone spraying of the clusters can help to develop seedless or parthenocarpic fruits. The results depend on the variety, the environmental conditions, the type of auxin and the concentration of the solution. High concentrations and potentially phytotoxic products, when used on sensitive varieties, cause fruit deformations such as : ribbed fruits, hollow end fruits, fruits with beak development.

The most interesting genetic disposition of natural parthenocarpic fruit development has been found in "Severianin" and is due to a higher natural auxin content. It seems also that parthenocarpic fruit development is better in spring than in autumn, while slight waterstress conditions are also favourable. The size of parthenocarpic fruits is in general smaller than that of normal ones.

A6. Fruit

The tomato fruit is a berry that varies greatly in shape, size and colour. In general, tomatoes grown in greenhouses are round, of medium size (2 to 5 locules) and red.

The size of the fruit not only depends on the number of ovules fertilized but also on other factors such as nutrition, irrigation, temperature and the number of locules. Large and ribbed fruits are in general obtained when nutrition and water are available at a sufficient level, under rather low temperatures with multilocular-type varieties, while higher temperatures, waterstress conditions and bilocular-type varieties give smaller and rounder fruits.

Quality is of paramount importance for fruit that is to be marketed, and is judged by a number of factors such as firmness, colour, flavour, transport resistance and storage ability. Firmness is linked to the genetic context as well as to the growing conditions. High greenhouse temperatures induce softness of the fruit. Firm fruits can be obtained at temperatures below 30°C, with adequate irrigation and high potassium/nitrogen ratios. Multilocular fruits are in general firmer than bilocular ones.

The **colour** must be as uniform as possible. In addition to the normal red colour, which is due to the lycopene content, other colours exist such as yellow, pink or crimson and high red.

It is not unusual for fruits to be unevenly ripened. Some of the most characteristic forms of ripening disorder are:

- **blotchy ripening**, marked by the presence of green zones and brown corky subepidermic zones in the ripe fruit, appears in general in early spring or late autumn productions. It seems to be linked to potassium and boron deficiency, to a marked imbalance between light (too low) and temperature (too high) and to low electrical conductivity of the soil or of the nutrient solution. However, there exist important varietal differences (e.g. Noria is very sensitive to this phenomenon while H63-5 and Vemone seem less affected).

- a **yellow collar** may develop on ripe fruits when the temperatures are too high (always > 25°C), if potassium fertilization is deficient, if vegetative growth is weak (bud growth or too severe pruning). Varieties of the uniform-green type seem to be less susceptible to yellow collar than the green type with dark green collar before maturation.

The **flavour** of the fruit depends essentially on the sugar and acid content. High levels of both are necessary to obtain good quality and good flavour. The pH of the fruit juice has to be below 4.4, while the total sugar content has to be above 4-4.5%. The acidity of the fruit is lower at high temperatures (30-35°C), and this leads to low flavour quality.

The keeping quality of the fruit is largely influenced by the activity of different enzymes, and the ripe fruit deteriorates very rapidly if temperatures are too high (>20°C).

B. Varieties

B1. Desirable characteristics

The ideal tomato variety should be of indeterminate growth habit with short internodes and good fruit-setting ability or parthe-nocarpic fruit formation (gene pat 2) at low temperatures. The plant should produce regular clusters (6-8 flowers) with medium-sized fruits of the 3-5 locular type (80-120 g), of homogeneous red colour, good flavour, offering firmness as well as good keeping and transport ability. The variety should possess good resistance to blotchy ripening, sunscald and fruit cracking.

Another type presenting the same characteristics should be of the semi-determinate or determinate growing type.

A wide range of disease-resistant varieties is now available and the choice between the various resistances depends on local conditions and consumer requirements.

The most common disorders and resistant varieties are :

- Verticillium: (gene Ve): hybrids can be of the heterozygote type;
- Fusarium: (genes I and I_2): homozygotic hybrids, especially at low temperatures;
- Meloidogyne sp. (gene Mi): fertility deficiencies can occur with this gene; for this reason heterozygotic hybrids are to be preferred;
- Tobacco mosaic virus (TMV): different genes exist (Tm1, Tm2 and $Tm2_2$). The genetic type which is mostly utilized is the $Tm2^2$ Tm1/++, but the ideal type would be $Tm2^2$ Tm1/Tm2 Tm1;
- Cladosporium fulvum: in the north Mediterranean region, resistance to Cladosporium fulvum is of importance: different genes exist : Cf2, Cf4, Cf5, Cf6 and Cf9. The best combination to date is obtained by Cf6 and Cf9, with different resistance mechanisms;
- Stemphylium solani: in the southern region, resistance to Stemphylium solani (gene Sm) can be of great interest.

- Corky root and Phytophthora: very few varieties present resistance to corky root (gene pyl) and Phytophtora infestans (gene Ph2). In the first case resistance is still linked to lower visual fruit quality while in the second case the resistance is incomplete, but disease development is slower and this allows the grower to take prevention action.

For other diseases, research on resistance and the introduction of resistance into cultivated varieties is in progress.
(Corynebacterium michiganense, Pseudomonas tomato, Cucumber mosaic virus, Trialeurodes vaporarium).

B2. Hybrids commonly grown

F.1 hybrids seem to be of particular interest in protected cultivation because they offer earlier and higher yields. Furthermore, resistance to various diseases can be introduced rather rapidly because in the tomato the most important genes are of the dominant type.

In regions affected by soil diseases, "Noria", and "Elcy", both VF2N are the most popular varieties for medium-sized fruits. Where salinity is a problem, the larger-sized "Carmello" is preferred.

Growers who frequently apply hormonal treatments to the tomato clusters particularly appreciate "Vemone" (Tm) and "Amphora" (VFC5Tm), because they are less susceptible to fruit deformation.

In some regions, "Futuria" (VFTm), "Viga" (VF2Tm), "Tango" (VFTm), "Fandango" (VF), "Tresor" (VFNTm) and "Belote" (VF) are preferred.

Among the **determinate** growth types the most commonly used varieties are: "Luca", "Quatuor", "Balca", "H 63-4" and especially "Prisca".

B3. Most popular varieties

Par. 6.1.3 focussed attention on some generalisations concerning the cultivars grown in the various regions of the Mediterranean zone. It is obviously impossible to mention here the cultivars of local origin, and only some of the main varieties belonging to the "international families" are listed below.

The qualitative study presented in the same paragraph shows the presence of a number of typical cultivars in some Mediterranean countries.

With regard to tomato cultivation a list of cultivars, together with the respective countries in which they are grown, is given below :

Carmello: Portugal, Spain, Lebanon, Egypt, Tunisia, Algeria, Morocco,...;
Vemone: France, Italy, Turkey, Tunisia, Algeria, Morocco,...;
Lucy: France, Turkey, Tunisia, Algeria,...;
Dombito: Portugal, Spain, Greece, Cyprus, Egypt;
H 63-5: France, Turkey, Tunisia, ...

C. Cultural practices

C1. Growth period and cycle

The tomato can be grown in a short or a long cropping cycle.

Short-cycle cropping is used for "catch" crops in the autumn and for the main crop in early spring. This type of cropping is mainly, though not exclusively, practised in the south Mediterranean region.

Long-cycle cropping is mostly used for winter-spring production in the south Mediterranean region or for autumn-winter and spring-summer productions in the north Mediterranean countries.

For short-cycle cropping, semi-determinate or determinate varieties can be very useful, but indeterminate varieties are used for all types of cropping in protected cultivation throughout the Mediterranean region.

C2. Types of cultivation

Tomatoes can be grown under various systems of protection: greenhouses, small plastic tunnels, windbreaks and mulching.

Mulching and/or **windbreaks** are used only for autumn or autumn-winter production, particularly in the south Mediterranean region.

Small tunnels are used for late spring (south) or early summer (north) production.

Greenhouses represent the classical type of protected cultivation.

Determinate or semi-determinate varieties are the best adapted to small tunnel cultivation, but in all other cases the indeterminate type is preferred.

C3. Cropping sequence

In general, the tomato is the principal crop and it is rarely used as a secondary or "catch" crop.

As most of the important crops cultivated in greenhouses belong to the Solanaceae or Cucurbitaceae and, therefore, present similar problems towards soil diseases (Fusarium and Verticillium wilt, root knot nematode, corky root, bacterial diseases), rotation is not really an efficient solution and growers have to turn to other techniques to control these diseases (varietal resistance, soil disinfection, biological control, etc...). It is only in the north Mediterranean regions that some important autumn crops belonging to other families are regularly grown (lettuce, snap beans).

Growers generally practice variable rotations, and in some cases (especially in the northern regions) the tendency is towards monoculture.

C4. Nursery

In general, young tomato plants are produced in nurseries. But in the sandy soils of desert regions (Israel, south Tunisia) they are propagated by direct seeding (1 or 2 seeds). This technique results in earlier and higher yields, better development and higher resistance to waterstress conditions.

In most Mediterranean countries, tomatoes are propagated in nurseries, in blocks or pots of various diameters, whilst in some north African countries (Tunisia, Algeria) they prefer the bare-rooted system combined with the sowing of 1 or 2 g. of seeds per m².

Nematode transmission is a major threat linked to the nursery system, even when the soil is sterilized.

High density or late planting (after the 4-leaf stage) often generate etiolated plants.

Blocks are generally preferred to pots (plastic, paper, peat) in most countries because they are less expensive and easier to handle. The containers are rather small in some countries (4 cm in Morocco) because of the lack of organic materials on the market. In other countries the pots are larger (7-8 cm), and peat is generally the basic material of the substrate mixture, though various other substrates may be encountered.

The 8-cm containers require planting to be done when the first cluster appears, while 10-12cm or 12-14cm blocks allow the plants to be maintained in the nursery until full development or even until flowering of the first cluster, provided that the spacing density is not too high.

Heating a nursery where the density is high (20-40 plants/m²) in order to delay planting in a cold greenhouse is more economic than heating a greenhouse where the density is normal.

C5. Direct seeding

In pots or blocks is less advantageous because lodging can be a real problem after irrigation. The best results are obtained with high-density seeding (3-10 g/m²) in the propagation stage followed by potting up when the first leaf appears.

Traditional techniques that were, at one time, widely used are now declining. For instance:

- **Protective inoculation** (=premunition) against TMV is no longer of interest because the new TMV-resistant varieties have a fairly good pollen production at low temperatures.

- **Grafting on KVNF-rootstocks**, which was a remedy for Verticillium or Fusarium-infected soils, is now largely replaced by the use of resistant varieties. Approach-grafting is still retained only for use against pyrenochaeta infection (corky root), though here, too, resistant varieties are under development.

  When TMV resistant varieties are being grafted, it is wise to have a TMV-resistant rootstock in order to prevent necrotic reactions at high temperatures. The seed industry has adopted thermotherapy, which makes it possible to obtain TMV-free seeds.

The optimum temperatures for **germination** are around 25°C, whilst 22-25°C are most favourable to cotyledon formation. From the appearance of the first leaf until planting, air temperatures should range between 12-15°C and 18-20°C. **Higher** temperatures combined with low light promote late appearance of the first cluster and cause etiolated growth. **Lower** temperatures result in strong plants with a reduced number of leaves before the first cluster, but growth is slower and flowering is delayed.

Plants in nurseries need regular **irrigation** according to the stage of development and the climate. Plants grown on a traditional nursery bed need less water than those in pots, but the water requirement is highest for those in blocks. Nevertheless, the substrate has a major influence on the quantity and frequency of irrigation.

C6. Planting and plant density

Plant density is generally 2-4 plants/m², depending on the vigour of the variety, the fertility of the substrate and the salinity of the soil and of the irrigation water. In cases of low fertility and saline connditions, the plant density is about 3.5-4 plants/m², whilst in normal conditions plant density should be 2.5 plants/m². In some special cases, high density planting (6-8 plants/m²) is preferred in order to obtain high yields within a short period.

Planting can be done in **individual rows** (1 x 0.25-0.40 m), i.e., 1m between two successive rows and 0.25-0.40 m between plants within the row. It is also possible to plant in **twin rows** (1.2 x 0.8 x 0.25-0.40 m), which is largely practised, as it permits drip irrigation or thermo-radiant mulch.

C7. Plant training and pruning

Staking: each plant is twisted around a string suspended from wires stretched horizontally 2-2.2 m above ground level. At the bottom, each string is fixed directly to the stem of the plant, or to another wire running along the ground, or also to a small stick driven into the ground close to each individual plant. Further north, the arched training technique is preferred since the cultivation period extends over a longer period (Fig.92a). When oblique training is practised (Fig.92b) the horizontal portion of the stems is supported by a wooden frame, 50 cm in height.

The **lateral shoots** of indeterminate varieties are removed regularly, but, if determinate varieties are used, suppression of the lateral shoots needs some care.

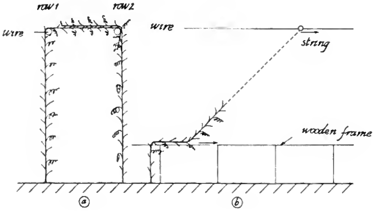

Fig. 92: Plant training and pruning

'Pinching' of the apex to limit the growth of the plant is only practised on indeterminate varieties. This pinching is in general carried out after 6-10 clusters in the southern regions and after 8-12 clusters further north. If the tomato is used as a catch crop, no more than 4-5 clusters are retained, and in high density cropping only 3 or 4 clusters are retained before pinching.

Defoliation, which allows better light conditions for the ripening of fruit and promotes early ripening as well as uniform colour development is started when the fourth cluster is setting. In general, only 4 clusters are maintained with foliage. Leaf thinning also permits better aeration and reduces the appearances of leaf diseases such as gray mould (*Botrytis cinerea*), tomato blight (*Phytophthora infestans*), tomato sclerotinia disease (*Sclerotinia sclerotiorum*), etc...

C8. Fertilization

The amounts of fertilizer applied for the tomato crop vary from one region to another, depending upon the richness of the soil, the climate, the irrigation technique and other factors.

In general, fertilizers are applied according to the total uptake of the crop. In spite of regional differences it is generally agreed that for the production of 1 ton of tomato fruit, the crop needs:

2.2 - 2.7 kg of N
0.7 - 0.9 kg of P_2O_5
3.0 - 3.9 kg of K_2O
5.0 - 6.0 kg of CaO
0.5 - 1.0 kg of MgO

Total fertilization is based on the estimated yield and the distribution depends upon the type of fertilizer.

- **Phosphorus** is generally incorporated during the preparation of the greenhouse soil, together with the organic fertilizers (manure and/or other sources).
- 50% of the total **potassium** is applied before planting and the rest during the first 10-12 weeks of the crop.
- **Nitrogen** is supplied every second week from crop emergence until about one month before the end of the cropping period.

High soil temperatures promote the uptake of nutrients and significantly influence earliness and total yield, but do not affect the nutrient uptake per ton of fruits, with the exception of MgO. Early suppression of the lateral shoots and early defoliation reduce the uptake of K_2O, P_2O_5 and MgO.

Only a complete knowledge of the absorption pattern of fertilizers can lead to the best and most efficient results.

C9. Irrigation

The global water requirement of a tomato crop under protected cultivation varies considerably with the type of crop, the growing period, the soil and the region characterized by a specific climate.

The young plant does not need large quantities of water, but from planting until the harvesting of the first fruits the individual plant needs - in the Mediterranean area - about 75 litres of water over a 60-day period. Daily requirements exceed 2 litres per plant from the flowering of the 2nd cluster, and the total requirement of a crop bearing six clusters is about 130 litres.

In the north Mediterranean region, classical furrow irrigation is being replaced by drip irrigation, though it remains widespread in North Africa. However, drip irrigation is the only way to achieve improved water efficiency and to obtain satisfactory development of the plants with less water.

Too much water can result in root asphyxia, which promotes deficiencies of MgO, P_2O_5 and N and also flower drop, while water deficiency results in higher salinity, which can promote blossom end rot. Alternating water excess and deficiency can result in fruit cracking.

C10. Harvesting

Classical harvesting is still the rule in most Mediterranean regions but France is experimenting with a harvest truck.

Fruits destined for the local market are generally picked at an early stage of maturity (at least orange), except in Italy, where picking is somewhat earlier in order to meet the demand for "green tomatoes". Fruits for export are picked earlier, when they first show colour.

Mechanized procedures for size grading and sorting are commonly used everywhere except in North Africa, where fruits destined for the home market are still graded manually (those for export are graded mechanically).

Ethrel may be used to promote maturation, especially for catch crops. Sprays applied to individual clusters or treatments applied to the whole plant can significantly increase the amount of ripe fruits harvested before the end of the cropping period. In general, solutions of 2,000 ppm of ethylene are sprayed 2 weeks before the scheduled harvest.

C11. Substrate culture and hydroponics

Both techniques offer solutions to disease problems associated with the soil and help to avoid soil sterilization. In general, "grow-bag" and "hydroponic" cropping result in earlier and higher yields, easier management of irrigation and fertilization, and a balance between fruit-set and growth.

Furthermore, these techniques require less energy to maintain the temperature of the root zone at the optimum level, and this is more important than the air temperature.

These systems are, however, less popular in the Mediterranean regions than further north because of the difficulties that may arise if control is not total (pH, conductivity, temperature, fertilization, irrigation,...). Indeed, "buffering" is low in the 'grow-bag' system and completely absent in the hydroponic one.

C12. Improvement of fruit-set

The vibration technique (either applied to individual clusters or generalized by pneumatic motor sprayer) can usefully compensate for a lack of pollen or a pollen release made difficult by excessive humidity or by low temperatures. At least one, and preferably two treatments, are recommended every third day in the case of electric cluster vibration whilst, for other techniques, a daily treatment is recommended.

Hormone sprays containing auxins can stimulate parthenocarpic fruit development if there is little or no functional pollen. The clusters are sprayed with various auxins when at least 3 or 4 flowers are open, and the operation may need repeating one week later. In normal cases, localized sprays are recommended; the concentration of the spray depends on the kind of auxin but, in general, a $5\,^{\circ}/_{\circ\circ}$ concentration of commercial product is advised. Sprays of ß-naphthoxy-acetic acid type are less aggressive than the -naphthyl acetic acid type, and can be applied even as foliar sprays. Hormone sprays can result in fruit deformation (ribbed or cat-faced fruits, empty and puffy weak fruits, beaking). Some varieties are very susceptible to fruit deformation with hormone sprays as compared with other cultivars (such as "Vemone", "Amphora" and "Elcy"...). The com-bination of one spray per cluster at $2.5\,^{\circ}/_{\circ\circ}$ concentration of commercial hormone with the cluster at vibration technique gives the best results.

D. Potential yield

If the crop is confined to 8 clusters, the potential yield is 10-12 kg/m^2 in south Mediterranean conditions and 12-15 kg/m^2 in north Mediterranean conditions. Higher yields can be obtained if the crop is based on a greater number of clusters, especially in the north Mediterranean regions.

The actual average yields are lower and do not exceed 7-8 kg/m^2 in North Africa and 10 kg/m^2 in the north Mediterranean countries.

Catch cropping in greenhouses or cropping under low tunnels results in a lower potential yield, and in general the harvest does not exceed 5-6 kg/m^2 under these conditions.

E. Major pests and diseases

- Tomato foot rot can be due to Rhizoctonia solani, Fusarium solani or Pythium infection of the substrate.

- Necrotic crop roots can develop in cool soils (14-18°C) due to Pyrenochaeta lycopersici (corky root) and, in warmer soils (25°C), by Colletotrichum coccodes.

- Collar rot can originate from Phytophtora nicotianae parasitica (10-15°C), Didymella lycopersici (15-20°C) and Botrytis cinerea.

- Wilt diseases arise from infection with Verticillium dahliae (18-20°C) or Fusarium oxysporum lycopersici (25-28°C).

- Bacterial canker is due to Corynebacterium michiganense.

Other diseases, affecting foliage and fruits under humid conditions, are: Alternaria solani, Phytophthora infestans (tomato blight), Botrytis cinerea (greymould) and Sclerotinia sclerotiorum. Some diseases only affect the leaves such as Stemphylium solani (humid and warm air conditions), Leveillula taurica (mildew; dry and warm air conditions) and Cladosporium fulvum (or Fulvia fulva) (warm and humid air).

Fungal diseases develop particularly well at low temperatures and high relative humidity. When they appear on the leaves or on the fruits, they can generally be checked by appropriate fungicides applied as foliar sprays, but good ventilation, even during the night, is very efficient in controlling most of them, since it reduces the relative humidity.

Various bacterial diseases may be present on tomatoes: Corynebacterium michiganense (bacterial canker), Pseudomonas corrugata (black pitch), Xanthomonas campestris vesicatoria, Pseudomonas syringae tomato (bacterial speck).

Bacterial diseases are quite difficult to control because, in general, they are transmitted by seeds and therefore, the production of seeds has to be submitted to severe control. Nevertheless, they can be limited by avoiding high humidity during the cropping period, and by applying copper treatments.

Various **virus** diseases or mosaics may also be present : the most important are TMV (Tobacco mosaic virus) and CMV (Cucumber mosaic virus); the first is transmissible by contact, the second by aphids.

Mycoplasma diseases of the tomato are "stolburd" and tomato yellow leaf curl. Both are transmitted by insects, respectively by leaf hopper and white fly (Bemisia tabaci). Mycoplasma diseases generally affect early autumn crops in the south Mediterranean region.

The root knot nematode (Meloidogyne incognita and M. javanica) can severely damage tomato crops, especially those grown in light soils with low organic matter content and in regions with relatively high soil temperatures during winter time. Soil sterilization is seldom successful, and the only way the infection can be checked seems to be by genetic control.

The **red spider mite** (Tetranychus urticae) can cause severe damage to the crop during the spring period.

Some **physiological diseases** such as silvering and leaf gall can occur if too low temperatures or too high humidities are maintained in the greenhouse.

Iron deficiency in the determinate growing varieties may coincide with the start of fruit maturation, especially when the plants are submitted to waterlogged conditions. Phosphorus deficiency occurs when the temperature is too low, whilst magnesium deficiency is due to excessive night temperatures. Calcium deficiency is particularly associated with the use of certain substrate culture.

F. Economics

The tomato crop is a relatively intensive one that demands much labour for several specific operations such as : training, pruning, defoliation, but also because of the relatively high yields and the relatively small size of the fruit.

Early production of good quality fruits is difficult to achieve without heating.

It is obviously impossible to establish an assessment of costs representative of tomato cultivation in the Mediterranean region as a whole since it varies with the regions and with the methods used. As an indication, the cost distribution for Tunisia is given below.

- greenhouse	36%
- covering material	25%
- fertilization + treatments	9%
- mechanical work	4%
- labour (manual work)	18%
- water	1%
- miscellaneous (seeds, etc.)	7%

G. Major restraints on crop production

One of the major problems related to the production of tomatoes is the production of **good quality early crops**. Earliness is definitely linked to the minimum as well as to the main night temperatures of the soil and of the air, while good quality also depends on the relative humidity at night. The problem of earliness is common to the Mediterranean region as a whole, but is more acutely felt in the north.

Total yields are in general lower in the southern regions because they are negatively linked with maximum air temperatures. Good ventilation of the greenhouse can increase the total yield in the south Mediterranean region.

Another important factor that influences yield is the control of diseases. This is in fact a multiple problem as it involves climatic control, genetic resistance, early detection and treatment.

6.2.1.2 PEPPER (Capsicum spp.)

A. General description

The pepper belongs to the genus Capsicum of the family Solanaceae.

The cultivated Capsicum belong to the following four species: C. annuum L., C. frutescens L., C. pendulum Willd, C. pubescens R. & P., but more especially to the first cited, C. annuum.

Only a few cultivated varieties belong to the species C. frutescens L. (such as: Tabasco, Uvila, Piquinita, etc ...), while cultivar descending from C. pendulum Willd and C. pubescens R & P are respectively cultivated in the mountains and on the coastal belts of Peru and Ecuador.

The cultivated varieties of the species Capsicum annuum L. are classed in several subspecies (or botanical varieties). Most of the varieties grown in protected cultivation bear large and non-pungent fruits and are of the grossum, cylindricum or latum type. In some cases they belong to the longum type, in which pungent and non-pungent varieties exist, while exceptionally the small, pungent acuminatum type is utilized.

The domesticated species and their wild relatives are similar since their fruit is a glossy berry or capsule, with a small or rather large cavity inside. Many cultivars can be sold when still green, but they become yellow and/or red if left on the plant until fully ripe.

Except for a few cultivated forms the taste of the fruit is pungent. The fruit of the paprika is not only used as a vegetable, but also as a spice (pungent varieties) and as a meat colourant (red powder after drying).

Peppers are grown in protected cultivation throughout the world, and in the Mediterranean area they constitute one of the most important crops in protected cultivation in many countries, coming right after the tomato, except in Tunisia, where pungent paprika and sweet pepper represent 55% of the total area devoted to protected cultivation.

The area allotted to sweet pepper cultivation in the southern part of Europe is actually about 7 000 ha for a production of about 260 000 t, much of which comes from Italy and Spain. Italy produces about 110 000 t from an area of about 2 900 ha; the yield per hectare is 36 t. In Spain the area is about 3 500 ha; the amount of production is 127 000 t with a yield of about 36 t/ha. Pepper cultivation is also present in Greece (12 000 t). In North Africa, Morocco has a production of sweet pepper that covers 200 ha and is intended for export, the non-exportable quality being consumed in the region. In Tunisia, the production of pungent pepper (paprika) reaches 27 000 t with an average yield of 30 t/ha.

B. The plant

The pepper plant is perennial, but it is usually cultivated as an annual crop. Only in some specific circumstances (northern Africa) it is grown over a 2-year period. When young, the paprika is herbaceous, but it soon becomes rather woody, so that in normal conditions the stem can support the epigeal part. Under protected cultivation the development of the plant is more vigorous and the fruits are larger, so that staking is necessary to prevent breaking of the branches.

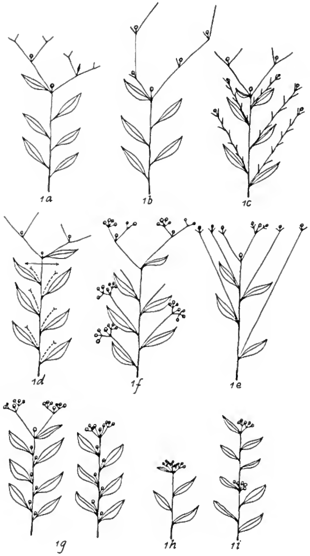

Fig. 93: Different growing habits of pepper

B1. Growing habit

The normal growing habit of the pepper is of the determinate type. After induction of a terminal flower, the main stem continues in mostly two, sometimes more, branches in the apical part, and each of these branches becomes determinate like the main shoot (See Fig. 93).

The appearance of this dichotomous development is influenced by the vigour of the different branches and by the length of the internodes.

When two branches are of equal vigour, a perfectly balanced plant develops, the height of which is determined by the length of the internodes. This short-internode type is undoubtedly better suited to outdoor cropping as well as cultivation under **small tunnels** (Fig. 93a), while in case of uneven vigour of the branches, the plant shows a natural adaptation for staked cultivation in the greenhouse (Fig. 93b). Normally, the main shoots as well as the lateral ones are allowed to grow without restriction (Fig. 93c), while pruning of the lateral shoots is necessary in protected cultivation.

Two main variants of this system are known :

- The first of these is similar to the normal type but the side shoots are absent or develop poorly under normal growing conditions; nevertheless the development of these lateral shoots can be promoted by pruning the main axis before branching (Fig. 93d).

- In the second variant the main axis, after branching, develops very short internodes and very soon ceases to grow. The lateral shoots reach the same height as the main one and become determinate, like the main axis (Fig. 93e). A fasciculate variation of this type is also used for early catch cropping (Fig. 93f).

A completely determinate growth type is obtained when the growth of the main shoot is inhibited and when the lateral ones do not appeaar at all (Fig. 93g).

Plants of the rosette type can be obtained with extremely short internodes. This type ceases to grow (Fig. 93h) or later develops a shoot with long internodes again ending in a rosette (Fig. 93i). As a rule, the rosette type produces no flowers at all.

B2. Roots

The main root of the pepper is a very vigorous one with an evenly lateral root development. The majority of the roots are located in the upper soil zone (0-25 cm) but they can reach a depth of 60-70 cm and a width of 50 cm. After transplanting, new adventitious roots appear on the injured primary root system, and the whole root system is more superficial. After ridging, adventitious roots may appear on the stem, but this phenomenon is not so frequent as with tomatoes.

The root mass is relatively small compared to the rest of the plant. In the juvenile stage the weight of the roots has a higher ratio (15-17%) than on the older plants where it falls to 7-9% of the total plant weight. Some wild relatives show a very deep and extensive root system and are of interest because of their drought tolerance.

B3. Leaves

The leaf blade may be ovate, elliptic or lanceolate, with an even edge, generally bare on the surface but sometimes more or less pilose. The blade is light or dark green, rarely violescent. The leaves vary considerably in size and in number from plant to plant. The leaf area of spice paprikas is normally much smaller than that of green pepper varieties.

B4. Flowers

In general, the sweet pepper has solitary flowers. Sometimes, in the case of pungent paprika, the flowers may develop in groups of 2 or 3, exceptionally in bunches numbering more than 5 (= fasciculated variation). The flowers grow on the apex of the shoots as well as in the axil of the leaves (on the main axis, there may be 2 or more at each axil). The style varies in length and the relative position of stigma and stamina places the anthers at a lower, higher or equal level in relation to the stigma. Self fertilization is more frequent in large fruited varieties (sweet peppers), while cross ferti-lization is more frequent with long, pointed spice paprikas because of respectively lower or higher positioning of the style in relation to the anthers. Each plant produces several hundred flowers and the rate of fruit-set can reach respectively 100% for the first flowers on the main shoot and 80% for the following ones while it falls markedly (to 20-30% and even to 10%) for the lateral shoots.

B5. Fruits

The pepper fruit is an inflated berry which, depending on the peduncle position (upright or drooping) and the fruit weight, can be upright, semi-upright (lateral) or pendent. Fruits in the lateral or pendent position are better covered by the leaves and more fully protected against sunscald, and picking is also easier.

The peduncle is continued inside the fruit by the central placenta, whose shape follows that of the fruit. In spice paprika types the peduncle is in general thinner than in the large-fruited ones.

The glands of pungent varieties contain capsicin; however, non-pungent fruits can be obtained on pungent varieties, especially during winter cultivation under protected cultivation. In spice paprika the capsicin content is at its highest level when the fruit reaches the green mature stage and becomes sooty.

Generally, the fruit develops very rapidly : 18 days elapse between setting and the green mature stage, and another 17 days are needed to reach the fully ripe stage (red or yellow fruit). But the interval between setting and the green mature stage depends on the variety and temperature conditions (3 to 10 weeks); similarly, the period needed to reach the full (mature) stage (red or yellow fruit) is very variable.

The shape of the fruit depends on the number of carpels and seeds. Spice paprika normally produces fruits with 2 or 3 carpels, while ball- or cylindrical-fruited types mostly have 3 or 4 carpels and tomato-shaped fruits even 5 carpels. The seed number, which is function of the fruit-set, has a major influence on fruit shape. Small quantities of seeds in the fruit normally result in smaller fruit. Some varieties are able to produce parthenocarpic fruits with fairly good shape, with a very small number of seeds or without any seeds at all. The parthenocarpic expression seems also to depend on the growing conditions.

The thickness of the pericarp is very important in the evaluation of varieties. In vegetable paprika and in sweet pepper a thick, fleshy pericarp is preferable, while for spice paprika the pericarp should be rather thin.

C. Ecologic requirements

C.1 Temperature

The pepper is one of the heat requiring vegetables cultivated in the Mediterranean area.

The temperature influences the growth and fertility of the plant, and even the size and the shape of the fruit : low temperatures are responsible for thinner, more pointed fruit while high temperatures produce stumpier berries. The minimum temperature for fruiting is about 15°C and the minimum biological temperature is about 11°C. Below this level the plant progressively undergoes irreversible damage which results in stunted growth, drop of young fruits and flowers, and necrosis of the leaves.

The optimum temperature for germination is 25-30°C; high temperatures (24-25°C during the day and 20-21°C at night) ensure improved vegetative growth in the early stages and good establishment after planting out. The soil temperature at planting time should be 22-24°C to promote root growth. In the subsequent phases the plant can grow very well at an air temperature reaching 28-30°C or more during the day, but high temperatures in the region of 35°C can be detrimental for flower formation, fruit-setting or fruit growth, particularly on old crops (young plants seem less sensitive to this phenomenon).

The best conditions for a satisfactory balance between vegetative growth and fruiting are 22-23°C during the day and of 18-19°C at night; the temperature of the soil should range from 15 to 20°C. In short, the pepper requires a high temperature for early vegetative growth and a rather lower temperature for flower formation; during fruit growth, air temperatures can go down to 15-17°C during the night.

Temperatures of 10-12°C inhibit growth of the fruits; temperatures above 35°C are also injurious.

The total number of degree-days from planting to first harvest can be put at 1 800 in cold greenhouses.

C2. Humidity

Pepper is rather exacting as far as relative humidity is concerned. It should range about 70-75%; more humid conditions should be avoided because the plant becomes very susceptible to botrytis; drier air conditions can hinder setting and cause flower abortion.

C3. Light

The species is not particularly sensitive to light duration, but it seems that flower formation could be enhanced by a medium day-length.

The pepper does not require a high light intensity; the leaf can reach its maximum photosynthetic activity at a light intensity of about 0.4 cal. $cm^{-2}.min^{-1}$

C4. Miscellaneous

Among other features of the plant which involve specific problems may be mentioned:

- **an irregular growth rate**; the daily production of fresh matter is estimated to be four times less intense during the first 120 days of the cycle than during the next thirty (exponential growth rate);
- **a high susceptibility of the root system to drying** and to waterlogging of the soil; a soil with good physical properties is a prerequisite;
- **an inevitable imbalance** between the volume of the epigeal part and the root system when the air temperatures are rather low, i.e. in the winter cycles the absorption of water and of minerals is in danger of being limited;
- a low level of **photosynthetic saturation** in the leaves; therefore, LAI (leaf area index) must be high to ensure good production.

D. Varieties

A few varieties are cultivated in some North African countries for the production of spicy green fruit. But, generally speaking, in protected cultivation in the Mediterranean area, varieties bearing prismatic, cubic or conic "sweet"-flavoured fruits are preferred.

The choice of variety is governed by the destination of the produce; there is a ready sale for cubic fruits in some countries (e.g. W. Germany) while other types are sought elsewhere (e.g. in Italy and France). As a result, the yield capacity, though higher in some varieties (e.g. prismatic fruits) is not the only criterion of selection.

The type of variety generally grown under protected cultivation in the Mediterranean region is of the normal determinate type, with short or medium-long internodes and equally developed branches. The fruits are cubic, cylindrical or prismatic, and have a very fleshy pericarp.

In northern Africa (Algeria and Tunisia) the most widely spread varietal type is a spice paprika with long piquant fruits and pointed apices; the pericarp is rather thin.

For catch cropping, fully determinate or fasciculate growth types have to be used. Both determinate and normal types with short internodes can be used for cultivation under small tunnels, in the first case for temporary protection only and in the second case for protection during the whole period.

F1 hybrids of sweet pepper are preferred, and this for many good reasons. Indeed, the seeds are readily available on the market; they are well adapted to the environmental conditions of plastic- and glass-covered houses, they have a high production capacity; the plants as well as the canopy are fairly uniform; they are early and resistant to some fungal and virus diseases. Thus the **higher cost** of hybrid seed is generally **justified**.

The prismatic-fruit hybrids of the type Lamuyo have been the most frequently cultivated ones up to now. Recent genetic improvements have led to the creation of new hybrids whose fruits resemble those of Lamuyo in shape but have a yellow flesh. Every seed firm has developed Lamuyo hybrids bearing cubic fruits (Yolo Wonder) which take on a yellowish or reddish colour when still immature. Particular efforts have also been made to create virus-resistant types. Most of them are TMV- resistant and, in addition, the market also supplies types resistant to other viruses (e.g. to PVY) or at least tolerant to some diseases (e.g. *Phytophthora capsici*). Considering the climatic conditions of the Mediterranean region, it is important to note that very high temperatures can prevent the expression of the genetic resistance to TMV which is based on a gene of hypersensitivity.

It must be mentioned (cf. § 6.1.3) that the following cultivars are cultivated in the regions mentioned after their name:

Lamuyo : Portugal, Spain, France, Italy, Greece, Lebanon, Egypt, Tunisia;
Sonar : Portugal, Spain, France, Italy, Tunisia, Morocco...;
Esterel: Tunisia, Algeria, Morocco...

Though great strides have already been made in the field of genetics, much remains to be done and efforts should be made to create varieties that would better serve the needs of protected cultivation in the Mediterranean region. Geneticists should endeavour to improve:

- the physiological behaviour under conditions of stress resulting from sharp variations in temperature and humidity;
- the ability to set fruit under conditions of low temperature and high humidity as well as with the use of parthenocarpy;
- the ability to produce marketable fruits even if they are parthenocarpic or if they have only a small number of seeds;
- the ability to reduce vegetative growth by improving the photosynthetic efficiency per unit of surface of leaves;
- resistance to diseases; TMV, CMV, PVY, TEV, *Verticillium*, *Phytophthora*, *Xanthomonas*, *Leveillula taurica* ("the white") and some nematodes (*Meloidogyne*);
- the capacity to concentrate ripening over a short period (suitability for catch cropping);
- the self stopping character without loss of shape and wall thickness of the fruits such as is nowadays the case in varieties of this type.

E. Cultural practices

E1. Growing cycles

The growing cycles are largely diversified even within the limits of a given region and, as a result, they cover a long period of the year. As a rule, cycles - in the Mediterranean region - begin in winter and harvesting starts in April. In Spain and in Morocco, planting may begin at the end of autumn, and harvesting takes place in February-March.

Earlier cycles begin in the autumn, harvesting taking place at the end of November.

Truly determinate or fasciculate cultivars allow catch cropping in autumn, with planting in September and harvesting from mid-November until mid-December.

Thus, the supply of produce from protected cultivation is almost continuous from the end of autumn to the beginning of the summer. During this period, the European market is dominated by produce from Spain, Italy and Morocco. Other countries (Greece, Tunisia) produce during winter and spring seasons.

This production calendar shows that, to some extent, peppers can also be grown (in non-heated shelters) under the Mediterranean climate during the cooler months of the year, but the yields are low in February-March.

In the southernmost areas of the Mediterranean region, the pepper is cultivated mainly under cold plastic houses or in walk-in tunnels, but outside the typical Mediterranean region and climate, for instance in northern Italy, crops are to be found in heated glasshouses.

There are some differences between countries, but they are related more to cropping cycles than to other biological and technical aspects of the cultivation.

E2. Crop sequence

The pepper generally comes first in the crop sequence; its cycle often extends over the whole period of use of the plastic house; sometimes it follows autumn-winter crops such as squash, or even lettuce or beans. It rarely follows other solanaceous or cucurbitaceous plants in view of the length of the cycle. Nevertheless, an early muskmelon or water melon crop may succeed an autumn catch crop of pepper.

E3. Propagation

The pepper is well adapted to sowing in a seed bed or in small containers followed by transplanting.

Sowing in a seed bed should be done so as to leave about 10 cm² around each future plant. As a gramme contains 100-150 seeds, no more than 6 grammes are necessary to cover one m². Sowing in small containers or in peat-pots is increasingly popular except in Algeria and Tunisia.

Plants are also propagated in specific heated houses because of the difficulty of providing the right conditions of temperature for germination and early growth of the plantlets in cold greenhouses during winter. As already stated, the temperature should be maintained at 24°C (maximum 28°C) until emergence, i.e. 12-15 days after sowing, and then be lowered. At this stage, watering, feeding and disease control are of paramount importance. Under correct environmental conditions the pepper is ready for transplanting eight to ten weeks after emergence. Planting may be done before the first flower bud appears, but for plants grown in pots it can be delayed until the first flower bud becomes visible.

E4. Planting

The soil must be carefully prepared before planting (physical characteristics as well as pest and weed control) and also be mulched.

Planting is done in single rows 1 m apart with 40-50 cm between seedlings (2-2.5 plants/m²), or in twin rows (distance between each row of a twin row : 70 cm; between twin rows themselves : 130 cm). In catch cropping, the plant density goes up to 5-8 plants/m².

Training and pruning are not as important as for tomatoes and egg-plants; consequently, pepper cultivation is less labour-demanding.

E5. Pruning

Under Mediterranean conditions (growing season, type of shelters) it is rarely necessary to control the growth of the plant by pruning. This is normally limited to the shoots that grow on the stem below the first branching or to some of the side shoots and leaves; on the other hand - if there are no problems of botrytis - a wide canopy is useful for peppers; in fact, the leaves have a rather low level of photosynthetic efficiency and, consequently, a large area of active leaves is necessary to produce sufficient dry matter : pruning thus proves necessary only in few cases (heated greenhouses, luxuriant growth ...).

Severe pruning may prove useful in some cases. It consists of the elimination of all the shoots and of most of the branches in winter with a view to counterbalancing the incidence of low temperatures (slow growth, absence of setting) and favouring growth with the occurrence of the first temperature rise. The plant is pruned immediately below the first branch. This technique is mainly applied to outdoor crops in mid-December, the crops being placed under small tunnels directly afterwards. Production starts again at the end of March.

E6. Training

In protected cultivation, the stem structure of pepper is often too weak to take the load of the plant, hence the need to train the plant. The methods may vary but one principle is to be observed : the leaves must always be exposed to the light and the canopy must always be ventilated.

Paprika staking needs no sophisticated material : either a 5 x 5 cm mesh net laid horizontally, or 2 or 3 lines of iron wires stretched on both sides of the row at different heights (30, 50 and 70 cm), will suffice.

E7. Fertilization

Fertilization requires particular care because the plant:

- has a root system rather sensitive to salt concentration;
- has high requirements for N, P_2O_5 and K_2O;
- requires a continuous high nitrogen level;
- grows unevenly : slowly in the first phases and very fast as the fruits begin to grow.

Following recent experiments carried out in France on sweet peppers, a yield of 40 t of **green peppers** removes from the soil some 350 kg of N, 100 kg of P_2O_5, 600 kg of K_2O and 50 kg of MgO. Of course, an equivalent production of **fully ripened fruits** exports greater quantities. Nutrient uptake is more intensive when the flowers begin to set. In all cases, N, P_2O_5 and K_2O must be supplied right from the time of planting.

E8 Irrigation

Since the root system is not extensive it does not tolerate the slightest water stress. As a result, water must be applied frequently but in small quantities. Drought and salinity both cause root scorch and favour fungal infection. On the other hand, waterlogging reduces the vigour of the plants.

The volume of irrigation - which varies with the duration of the cycle, the growing season and the distribution methods - ranges from 4 000 to more than 10 000 m³/ha. A kg of fresh fruit is estimated to consume 70 to 100 l water.

Drip irrigation is to be preferred as this system saves water and favours regular absorption by the roots.

It should be remembered that peppers are more sensitive to salinity than other solanaceae; a salinity of 1.8% in the soil and of 1.2% in the water can reduce the yield by 25%.

E9. Other practices

Some advanced practices are difficult to develop in the Mediterranean region (carbon dioxide enrichment, artificial lighting or growing systems on substrates other than soil). Growth regulators are hardly every used. Hormonal sprays of the auxin type have no clear effect; they are quite difficult to apply on individual flowering plants such as the pepper, not to mention the small fruited spice paprika type, while overall treatments of the whole plant induce injurious deformations of the foliage.

After treatment of the flowers an abnormal "point" development may appear at the apex; this detracts considerably from the value of the fruits of the Lamuyo or Yolo Wonder types.

F. Major pests and diseases

The pepper is susceptible to a large number of pests and diseases. In protected cultivation more specific attention must be given to some viruses, fungi, bacteria, insects and nematodes. Blossom-end rot of the fruit is another threat, mainly when salinity in the soil or in the irrigation water is too high or when fertilizers are used to excess.

Up to now the capacity for genetics to improve resistance to these pests and diseases has been restricted to some viruses and fungi. The resistances obtained are neither total nor stable.

So the pepper, more than any other crop, needs careful control of the soil-borne parasites, through soil sterilization (Methyl bromide) or through other specific chemicals.

Other possibilities may be noted, e.g.:

- the use of **seeds treated chemically** (trisodium phosphate) with a view to inactivating the TMV virus; but this treatment can reduce the germination capacity of the seeds significantly;
- **the position of the pepper in the crop sequence**: first and immediately after sterilization (prevention of TMV, Rhyzoctonia solani, Fusarium solani, nematodes and Phytophthora capsici;
- **good ventilation of the greenhouse** to prevent the very dangerous Botrytis;
- a **drip irrigation** system to avoid the spread of Phytophthora capsici aplanoconides.

Preventive pest control by means of chemicals is normally necessary in plastic houses against Botrytis cinerea, Rhyzoctonia solani, Verticillium dahliae, Leveillula taurica ..., which find in the microclimate of the protected cultivation of the Mediterranean regions favourable conditions for their development.

Curative control can be used to limit the diffusion of Cercospora spp., Alternaria spp., Collectotrichum spp., Fusarium spp., Sclerotium and Sclerotinia, Xanthomonas.

Trialeurodes vaporariorum (white fly) and various Aphis species - able to transport viruses - are, together with spiders, some of the most frequent and important pests. Alternatives to chemicals have recently been suggested to control them, e.g., biological control, chromo-attractive techniques.

G. Economics

Sweet pepper can be marketed when green or when fully ripe (red or yellow). **Picking green fruits** is not always easy as the fruits harvested before they have reached **maximum** growth neither hold nor travel well. The fruits should not be picked until the surface has turned glossy and darker green. Fruits remaining on the plant require another 3 weeks to become fully red or yellow.

Fully-coloured sweet peppers return a higher profit than green fruits; but picking at the fully ripe stage causes an estimated loss of yield by 20-25%. So the choice of picking stage is a problem to be solved on the basis of biological and economic considerations. During the winter and spring seasons in the Mediterranean area it is more common to harvest green because the price for the produce offered earlier on the market may be more attractive. This trend has induced some growers to treat green fruits with ethylene (2 000-4 000 ppm) to enhance the appearance of colouration.

Harvesting should be done carefully, as harsh breaking of the peduncle damages the fruits and the young shoots.

Normally one harvest per week is sufficient.

When picked, the fruits must be marketed very quickly; good keeping quality over a period of up to 10 days can only be expected at reduced temperatures (8-10°C) and if the relative humidity is 90-95%.

An economic study of pepper cultivation is virtually impossible: the elements to take into consideration vary too much:

- There are differences between countries and between the types of shelters;

- Even within a limited area the types of farms and their management, the level of production, the price in the course of years and even in the course of a given year are hardly comparable.

Some features can however contribute to making a rough economic evaluation.

a. The pepper is less **labour demanding** than other important solanaceae such as the **tomato** and the **egg-plant**; these two crops can require about

5 000 hours of labour per hectare, while the pepper requires perhaps half of this time;

b. The curve of labour requirement is rather irregular all along the cycle;

c. the price of the produce decreases significantly from the end of winter to late spring; the ratio is, normally, three in February to one in June;

d. the average yield per hectare varies significantly, above all according to the period and duration of cropping;

e. the costs vary considerably between countries; a rough estimate is: about 25% of the total for materials, about 50% for labour and services, and 25% for all other charges. To be more precise, it is necessary to consider a particular case : in Tunisia, for example, it has been calculated that:

- greenhouse costs: 41%
- plastic sheets: 29%
- fertilization + treatments: 7%
- mechanical and manual work: 6%
- labour costs: 14%
- water: 1%
- miscellaneous (seeds, etc.): 2%

f. the production cost per unit of yield can be put at 80-85% of the cost of tomato and egg-plant production.

H. Major restraints

The major obstacles to larger yields seem related to environmental and, above all, climatic conditions rather than to the yield capacity of the plant. Indeed, the yields may vary considerably.

Protected cultivation in plastic houses during the winter and spring periods is by no means the best way to achieve a regular trend of physiological processes. The main problems are related to low temperatures, which hamper vegetative growth and regular setting, to high temperatures which cause flower drop, and to high humidity, which has adverse effects on both vegetative and reproductive activity.

Problems related to day length and light intensity are less important.

The best way in which to increase production is to acquire a greater knowledge of the physiological processes involved and to use plants better adapted to the stress conditions analyzed above.

6.2.1.3 . MUSKMELON (Cucumis melo)

A. General description

A1. Roots

The root system of the muskmelon is extensive but shallow, with a strong tap-root readily giving rise to numerous secondary and lateral roots. There is no adventitious root formation, hence the root system regenerates with difficulty when destroyed. For this reason it should not be transplanted bare-rooted; it is essential either to use pots or to plant seeds directly in the soil.

A2. Stem-leaves

The main axis of the stem is a sympodium which readily branches into primary and secondary branches. Although it is prostrate, the stem can climb with the help of tendrils borne at the axil of the leaves. The training of muskmelon is an intensive labour operation, not only because climbing of the plant must be ensured but also owing to the need to prune the lateral branches so as to ensure the predominance of the main axis.

A3. Flowers

According to the type of flowers, muskmelon cultivars can be divided into monoecious, bearing separate staminate and pistillate flowers on the same plant, and andromonoecious, bearing staminate and hermaphrodite flowers.

The flowers are borne in the axil of the leaves; the male flowers are much more numerous than either of the other types. The ratio between pistillate (female) or hermaphrodite and staminate (male) flowers depends on the cultivar temperature-light interactions and the effect of growth regulators. **Long days, high temperatures** and **gibberellins** increase the number of staminate flowers whereas short days, low temperatures and auxins induce the formation of pistillate or hermaphrodite flowers.

The formation of female flowers is inversely proportional to the vigour of the plant. The more vigorous the cultivar, the later do the first female flowers appear. So, the ratio of female to male flowers increases from the main axis to the lateral branches and from the bottom to the top of the plant. An efficient system to improve earliness is to prune in order to stimulate branching which will "favour" female flower production.

A4. Pollination

Pollination of muskmelon is entomophilous. It is essential for monoecious cultivars to achieve pollen transfer from the male to the female flowers. In andromonoecious cultivars, although there is no incompatibility between pollen and ovary in the hermaphrodite flowers, artificial pollination by honeybees is recommended because dehiscence of the stamens may not coincide with receptivity of the stigma, or the pollen may be insufficient.

A temperature of 18-20°C is necessary for the opening of pollen sacs, and this is readily achieved in a greenhouse. But in very early crops if pollination is not possible, even with honeybees, because there is no pollen or it cannot be released, fruit setting may to a certain extent be increased by application of auxin (4 CPA) or cytokinin (Benzyladenin) to the flowers. This is a time-consuming operation which often proves unnecessary: too early fruit-setting under unfavourable temperature conditions must be avoided. As the vegetative growth is very weak, yields will be low and the setting of later fruits will be inhibited.

Good pollination is also important in order to ensure uniform fertilization of the ovules, otherwise fruits may be malformed owing to differences in growth of the pericarp. There is a high correlation between the number of seeds per fruit and its weight. Some cultivars like 'Ogen', for instance, can be more or less parthenocarpic, but this correlation still holds true. Thus pollination is a good way to increase fruit weight and productivity.

A5. Fruit drop

Fruit drop in muskmelon is very frequent. It may happen very early, just after flower anthesis or later on when the fruits are 3-5 cm long, even if the quantity of seeds is sufficient. Usually only a few fruits per plant develop fully: 3-4 in small-fruited cultivars and 2-3 in the larger fruited ones.

Fruit drop depends on:

- competition among fruits;
- competition between the fruits and the vegetative apices;
- the relation between the number of leaves and the number of fruits.

A minimum number of leaves is thus necessary to feed each fruit. In this competitive situation, the first fruits to set inhibit the setting and growth of the later ones, but when the older fruits have been picked, further fruits can set at the top of the plant. To decrease the importance of this phenomenon, much attention should be paid to plant nutrition, leaf destruction by parasites and LAI (leaf area index). The greater the number of leaves exposed to light, the more and heavier fruits will be able to grow.

A6. Fruit

Growth of the muskmelon fruit follows a sigmoid-type curve, and takes 30 to 50 days from setting to ripening, depending on cultivar and environment. The fruit has a climacteric point (higher CO_2 release when ripe), and its ripening process may be hastened by ethylene application. The sooner it is applied, the earlier does the fruit ripen but the lower is its sugar content and quality.

Fruit flavour and sweetness are difficult to characterize because too many chemical compounds are involved. However, in most situations, sweetness is closely related to sugar content. Thus, the Brix value of fruit juice is usually used to evaluate its quality.

B. Ecological requirements

In protected crops, muskmelon is one of the crops with highest heat and light requirements. So, it is grown with difficulty in wintertime, even in heated greenhouses.

Light is not only important for plant growth but also particularly for fruit quality. Plants submitted to low light intensity always produce small and unsweet fruits. This also happens when leaves are damaged by pests or diseases, since this restricts sugar production by the foliage.

The most important temperatures (°C) for muskmelon are :

	minimum	optimum
vegetative growth	12	22-26
seed germination	15	24-35
soil temperature	10	18-20
fruit ripening	-	25-30

Low temperatures reduce growth and hasten female flower formation. In early spring, in unheated greenhouses, the plants are short with small leaves, in contrast to those grown in summer.

Excessively high temperatures (above 30°C) increase respiration and accelerate fruit ripening, so that the fruits become yellow too early, have a low sugar content and are of poor quality.

Soil temperature has a considerable influence on plant growth and on water and nutrient absorption. So, plastic mulching with transparent PE film may successfully be used in spring to increase the soil temperature.

C. Varieties

The muskmelon is polymorphous and, therefore, the cultivars are difficult to classify. The most important botanical varieties of Cucumis melo are: var. cantalupensis, var. saccharinus, var. reticulatus and var. inodorus. The cultivars are hybrids of these botanical varieties, hence the diversity is very high. It is difficult to find cultivars belonging only to one of these groups.

The choice of cultivars is dictated by market preferences. As there are many types of fruits with regard to size, form (round or oval), type of epiderm (smooth or rough) and colour (yellow or green, green or salmon flesh, etc.) the grower must choose the type of fruit that sells best. Subsequent criteria are disease resistance (mainly to soil diseases - cf. §5.4), plant productivity, earliness, climatic adaptation, fruit resistance to handling...

For protected cultivation in the Mediterranean region it is the cantaloup-type cultivars, with round fruits having rough or smooth green skin and weighing about 0.8 to 1 kg, that are most widely used.

Although many open-pollinated cultivars are still grown, the F1 hybrids are increasing in importance owing to their higher productivity and good plant characteristics.

In addition to working on productivity, the breeding programmes are mainly focussing on disease resistances : fusarium, powdery mildew, cucumber virus 1 and nematodes, fruit quality and fruit resistance to handling.

Few melon cultivars are grown simultaneously in a relatively large number of different Mediterranean countries. The choice is dictated by nothing but the local taste:

- Galia: Portugal, Spain, Greece, Turkey, Cyprus, ...;
- Jivaro: Tunisia, Algeria, Morocco, ...;
- Vedrantais: France, Algeria.

D. Cultural practices

D1. Planting time

In protected cultivation the muskmelon is usually a spring crop because its climatic requirements do not allow it to be grown in wintertime and competition with late open-air crops reduces the autumn prices. In the cropping sequence it may follow a winter crop (lettuce) or an autumn one such as tomato, greenbeans, etc.

The planting time depends on the region. However, in Mediterranean conditions, even in the most favourable areas, conditions are not suitable for planting before mid-February without heating.

D2. Cultivation systems

Two systems may be followed : the **flat crop** and the **climbing one**. The former is cheaper; it may be grown in lighter greenhouses without training wires and requires less labour but yields less. Average yields in good conditions are about 4 to 5 kg/m² for flat crops and 6 to 7 kg/m² for climbing ones. Generally, the flat crop system allows an earlier (but lower) production. For some markets, the fruits from climbing plants are considered of better quality because they are not in contact with the ground. For others they are of lesser quality because they are supposed to be "artificially" grown. Consumers can distinguish them by the position of the peduncle.

D3. Plant density

Average plant density is about 1.8 plants per m² for flat and 2.5 for climbing crops. It depends on plant vigour, on light and on the time of year. Higher densities are used for less vigorous plants and good light conditions. The higher the plant density, the higher the yield per m² but the lower the number of fruits per plant and the size of fruits.

D4. Pruning

Before describing the most important systems, some general remarks about pruning may be given:

- pruning stimulates branching and reduces plant vigour, hence anticipating female flower formation;
- the more drastic the pruning, the greater the reduction of vigour. Vigorous cultivars should be pruned intensively;
- pruning influences earliness rather than the actual yield;
- the choice of a pruning system depends on the planting distance, cultivar, environment, etc ...; therefore it is impossible to say which pruning system is the best for all conditions.

Now, **flat crops** are usually **not** pruned; if they are, only the main stem is stopped above the second or third leaf in order to stimulate secondary branching. More intensive systems are labour-consuming, not balanced by profitable earliness. If necessary, fruits may be thinned in order to reduce their number per plant and to increase their size and quality.

Climbing crops must be pruned (see Fig. 94).

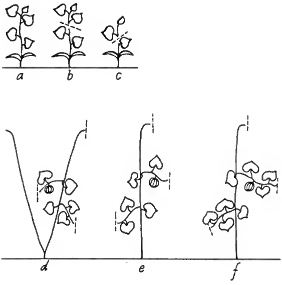

Fig. 94: Scheme of vertical muskmelon pruning system

a – Young plant not stopped
b – Young plant stopped at the 2nd leaf
c – Young plant stopped at the 1st leaf
d – Plant trained with 2 main stems
e – Secondary branches stopped after the first fruit
f – Secondary branches stopped 2 leaves afterwards

- (a) the plant may not be stopped and the main stem is trained up;
- (b) the main axis may be cut above the first leaf;
- (c) or the main axis may be cut above the second leaf.

Stopping the main axis to use a secondary branch instead induces earliness, but may be useless when the first female flowers appear very early. In this case they may be removed to avoid competition with plant growth. One or two main axes may be trained per plant. Single-stem training is the commonest system, but if two stems are retained – as in (d) for vigorous cultivars – vigour is reduced and earliness is increased. The secondary branches appearing from the main axis may be stopped just after the first fruit (e) or two leaves afterwards (f). The first system reduces the number of leaves and should be used with good light and high plant density.

D5. Irrigation

Adequate irrigation increases yield and fruit quality. The amount of water to supply can be based on PET (potential evapotranspiration). As the plant needs change during the cropping cycle, the quantities given in a sunny region should be:

- 40 to 90% of PET during the growth period;
- 100% of PET from blossom to full sized fruits;
- 95% of PET during ripening.

Excess water when fruits are ripening may cause fruit cracking.

D6. Nutritive requirements

A muskmelon yield of 60 t/ha removes about 200 kg of N, 80 kg P_2O_5, 400 kg of K_2O. Nutrient uptake changes along the cropping period but it may be considered proportional to water absorption. Excess N induces vigour and reduces earliness. **Potassium** increases sugar formation and, therefore, improves fruit quality; it is very helpful under low light conditions. **Molybdenum** is one of the most important minor elements; plant growth may be checked owing to Mo deficiency.

D7. Nursery

No specific comments are necessary on nurseries and seedling growth, except for the impossibility of transplanting bare-rooted muskmelon and its high temperature requirements. Much care should be taken when handling young plants to avoid wounding the roots, because they are very susceptible to rotting. Nurseries must be heated or plant emergence will be delayed and irregular.

When muskmelons are to be planted into infected soils, they may be grafted on Benincasa cerifera or Cucurbita ficifolia, the latter having some affinity problems with cultivated varieties.

Low plastic tunnels are widely used even in walk-in tunnels because the muskmelon is well adapted to them as a flat plant. In spring, the tunnels may be removed during the second half of the cropping cycle. Growing practices are similar to those for a flat crop in a greenhouse, but the plant density is lower (1 plant/m²), and so are the yields.

E. Major pests and diseases

The muskmelon is susceptible to many diseases, insects, mites, etc., like other protected crops. However, two of them require special attention owing to their specificity :

Fusarium - This is the most important disease, resulting from plant infection by Fusarium oxysporum var. melonis. This vascular fungus lives in the soil and gets into the plant through the root system. There are five physiologic races already identified whose resistance in plants is controlled by a polygene system. This makes breeding programmes for resistant cultivars long and difficult. Symptoms depend on the race which is present but plants often show gummosis or yellowing followed by a quick decline. The crop may be completely lost. This fungus produces spores which are quite resistant to soil fumigants and steam sterilization so that it is difficult to disinfect the soil completely. The effective means of control are the use of resistant cultivars or grafting on appropriate rootstocks. Recently some good results have been obtained with soil "solarization" at certain latitudes.

Powdery mildew (Erisiphe spp.) - This often occurs in melon crops. Four species develop very rapidly under greenhouse climatic conditions. The plants show leaves covered with a mycelium similar to white powder. Some resistant cultivars are available, but modern systemic fungicides offer efficient control.

Other common diseases are Verticillium in the soil, Ascochyta on the stems and leaves, Anthracnose on the fruit, Cucumber Virus 1.

F. Major restraints

The cost of muskmelon production per unit of surface is similar to that for tomato. However, pruning and training have a great influence on the cost owing to their high labour requirements: climbing crops may sometimes be less profitable than flat ones because their high yield does not balance the increased labour cost.

Picking is quite cheap, being easier for trained plants than for flat ones.

The major restraints on muskmelon expansion largely depend on the country and the region. Some of them may be: low market flexibility, fusarium-infected soil, and high requirements regarding climate.

6.2.1.4 EGG-PLANT (Solanum melongena L.)

A. General description

The egg-plant (aubergine) is a herbaceous annual plant of the family Solanaceae.

A1. Root

The root system is creeping and shallow in protected cultivation, and for this reason the egg-plant can be grown either in deep or shallow soils.

A2. Stem

The upright stem develops into thorned branches, with greyish entire, sometimes thorned leaves.

A3. Flower

The flower is violet, has an accrescent calyx, grows isolated or in trusses of 2 or 3 but only one of them develops into a normal-sized fruit, the others becoming undersized berries.

The fleshy berries of the different cultivars vary in shape and colour: long, globular, pear-shaped, black, purple, white, speckled (mottled), etc...

A4. Climate requirements

The egg-plant is a thermophilous subtropical crop.

Its temperature requirements are:

lethal minimum T°	0 - 2°C
biological minimum T°	10 - 12°C
maximum T°	32 - 35°C
optimum night T°	17 - 22°C
day T°	22 - 27°C
germination minimum T°	12 - 15°C
optimum T°	20 - 30°C
maximum T°	35°C

It is a high light-demanding crop. In poor light conditions fruit-set is difficult and vegetative development is stimulated (etiolation).

Excessive humidity makes it difficult to obtain good flowering and fruit-set. Adequate levels are from 50 to 65%, depending on the temperature.

The greenhouse climate in the Mediterranean region during wintertime suffers generally from a decrease of light, low night temperatures and high humidity. These conditions do not favour good development and growth, especially during the young stage, and result in flower abnormalities, leaf hypertrophy, excessive growth and poor fruit-set. The southern Mediterranean regions are less affected than the northern ones. Furthermore, a highly humid environment decreases the photosynthetic activity in some cultivars as a result of the partial closing of the stomata, which have reached their water saturation stage.

This reduces CO_2 uptake (*) and the production of sugar and dry matter decreases.

Varieties of the far eastern and meridional regions seem to be better adapted than the Mediterranean ones.

A5. Soil

Adaptation to a wide range of soils is a quality of this plant, although soils of pH 6-7 and of medium texture are best suited to its requirements. Excessive soil moisture is harmful since it produces root problems, especially in young plants.

B. Varieties

B1. Desirable characteristics

The plant adapted to protected cultivation should be of limited growth, with no tendency to hypertrophy, provide some parthenocarpic ability, good flowering and fruiting in winter conditions, be resistant to *Verticillium dahliae*, have a high yield capacity and produce fruit of good quality.

B2. Cultivars

Among the most frequently grown cultivars are the following:

- Round fruit (Meridional group);

  Bonica F_1, Mission Bell F_1, Midnite F_1 (dark purple)

- Long fruit (Occidental group);

  Baluroi F_1, Eras F_1, Marfa F_1 (dark purple)

B3. Market requirements

Every market has its particular preferences. For instance, the Spanish market likes round dark fruits, whereas the French one demands long fruits. Some more local markets have a special preference for violet or green-mottled white fruits, like the cultivar "listada de Gandia" along the eastern coast of Spain.

Each country seems to have adopted one or other type of cultivar. The varieties most frequently met are:

Baluroi : Spain, Italy, Turkey, Cyprus, Tunisia, Algeria, Morocco;
Bonica : Portugal, Spain, Greece, Cyprus, Tunisia, Morocco. ...

(*) Another explanation is that high humidity reduces transpiration and, consequently water and nutrient uptake, because the saturation deficit is very low and so is the difference between the water tension inside and outside the leaves.

C. Cultural practices

C1. Growing period and cycle

Depending on the region, the cycle starts with November-to-January transplantings intended for early spring production (from March until June-July). In some regions the plants are then severely pruned to get a second harvest during the autumn months. In the northern regions, late transplantings yield fruit from May to the end of summer.

In another cycle, transplanting takes place from August to September, and the harvest period extends from October to May-June. Other types of growing are also practised, e.g. under low tunnels or on mulches, but these are less common than greenhouse cultivation.

C2. Position in the crop sequence

Owing to its long-cycle crop character, it has the main position in the sequence. It can be preceded by a short autumn crop such as cucumber or gladiolus and, if pruned for an extra autumn yield, it can be followed by melon, short-fruited cucumber or water melon.

C3. Plant production

When pricking out is not practised, it is useful to seed on 8 x 8 x 8 cm pots and to transplant at the 5 or 6-leaf stage, although seeding on smaller pots, 5 x 5 x 5 cm and transplanting at 3 - 4 leaves works well and reduces the volume of substrate, which is important in the Mediterranean. It usually takes 1.5 - 2 months from sowing to planting during autumn and winter.

As Verticillium and Nematode-resistant varieties are not yet available among the cultivated cultivars, grafting on resistant rootstocks can be a solution. Grafting can be done on KVFN-tomato varieties or on some wild Solanum species such as S. sodomeum, S. torvum, S. syssimbrifolium. When grafted on a tomato rootstock the crop becomes earlier than a normal egg-plant because of the lower heat requirements of tomatoes; but staking is necessary. Grafting on S. sodomeum gives no staking problems and plants are more drought-resistant but harvesting is delayed.

The egg-plant is fairly sensitive to low temperatures, and it can prove worthwhile to arrange simple and relatively cheap means of protection against cold in the propagation house:

a. forced air heating to assure 10-11°C minimum;
b. special thermo-isolating covering materials (IR-PE, PVC, EVA);
c. double-wall coverings;
d. low tunnels within the greenhouse.

Double wall covering and low tunnels in the greenhouse make it necessary to give particular attention to ventilation in order to avoid excessive temperatures which, associated with a lack of light, would result in weak plants.

In order to control growth rate of young plants, the fertilization, irrigation and air humidity should be properly monitored.

C4. Soil preparation

As a general comment, some 8 kg/m² of manure, three months before planting, and some 100 kg of N, 150-180 kg of P_2O_5, 100 kg of K_2O and 80 kg of

MgO per hectare can be used as base dressing, followed by deep ploughing and some rotary tillage.

C5. Plant spacing

Two plants per m² is an adequate density. The distance between rows is from 0.90 to 1.00 m, and between plants from 0.50 to 0.60 m.

C6. Training and pruning

The plant has an upright habit, and some horizontal strings fixed to the plants as they grow are enough to support them and keep the paths open for the harvesting operations. Pruning has no important effect on yield, but is justified as a good means to ventilate the canopy and lessen the risk from Botrytis cinerea and Sclerotinia.

A good pruning system consists in removing the side shoots up to the first flower. Afterwards, two branches develop to make up the structure of the plant. Periodic removal of shoots in the inner part of the plant and of the oldest leaves suffices to allow good air exchange.

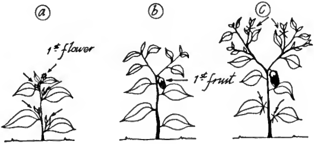

Fig. 95: Training and pruning egg-plant

a. Removal of side shoots below the first flower;
b. Training to two stems
c. Removal of inner shoots and old leaves.

C7. Fertilization

General fertilization rates for top dressing are 300 kg each of N and K_2O per hectare from the setting of the first fruits.

C8. Watering

Water supply should be restricted until the first fruit-setting. After that, watering must be regular and without restriction, with between 4 000 and 7 000 m³/ha of water per year.

C9. Fruiting

* During the cold season certain abnormalities affect fruit-setting:

- abnormal development of the ovary, and limitations in the fertility of pollen or in the fertilization processes, may occur due to low temperatures;
- anther dehiscence and pollen transfer to the stigma are difficult when the humidity is high.

* Several responses can help to offset the difficulties mentioned above:

- ventilation to reduce humidity and improve pollination;
- use of Meridional-type cultivars which have the capacity to develop normal fruits even if pollination is poor;
- spraying the flowers with growth substances to set the fruit during the coldest periods, and subsequent use of knapsack dusters to vibrate the flowers during the warmest hours of the day to improve pollination.

C10. Harvesting and Marketing

The fruit is harvested when the colour is uniform and bright, when the weight ranges from 190 to 200 g, and before the seeds develop. Picking is done with pruning shears, retaining 2-3 cm of stalk and the calyx. Handling must be careful, since bruising adversely affects shipping and storage. The fruit is graded according to regularity of shape:

- Quite regular fruit falls into **category N° 1** (round cvs : 5 or 6 units per kg, long-fruit varieties : 6 to 8 per kg)
- **Category N° 2** includes less uniform fruits.

Packaging is done in 10 kg boxes or trays, with paper. Storage for some 10 days is possible at 4-5°C.

D. Major pests and diseases

Mysus persicae (peat potato aphid), Meloidogyne spp. (root knot nematode), Trialeurodes vaporariorum (white fly). Leptinotarsa decemlineata (potato beetle) - only in the northern Mediterranean regions - Tetranychus urticae (spider mite). Pythium spp., Verticillium dahliae, Botrytis cinerea and Sclerotinia sclerotiorum are some of the major egg-plant pests and diseases in protected cultivation.

E. Economics

In protected cultivation, and depending on the cycle and the growing system, the yield can vary from 5 to 10 kg per m².

Labour costs account for over 60% of the total expense of egg-plant cultivation. The plant material represents 10 to 15% and the agrochemicals plus miscellaneous expenses (water, tillage, etc.) amount to some 20%.

F. Major restraints

This is a minor crop compared with tomatoes and peppers. The main factor limiting its development is the very low rate of increase in demand. This also explains why the breeding programmes of seed companies devote so little attention to this crop. In fact, very few new cultivars are introduced on to the market each year.

On the other hand, the high humidity prevailing in greenhouses favours the incidence of Botrytis, especially on the flowers and young fruits, and thus greatly affects yields. Botrytis control is difficult and expensive.

Finally, the sensitivity of the egg-plant to Verticillium dahliae is another factor which, together with the high labour requirement of the crop, limits its development and favours other, more competitive crops.

6.2.1.5 CUCUMBER (Cucumis sativus L.)

A. General description

The cucumber is a herbaceous annual plant that belongs to the family Cucurbitaceae.

A1. Roots

The main root axis gives rise to a dense fibrous and long shallow root system; there are no adventitious roots : the cucumber cannot be transplanted bare-rooted.

A2. Stem

The stem is polygonal, herbaceous, and has an indeterminate habit. It climbs, when trained with vertical supports, with the help of its tendrils.

A3. Flowers

The yellow flowers arise in the leaf axils.

The cucumber is a typical monoecious plant, although andromonoecious, dioecious or hermaphrodite types can also be found. The most commonly cultivated varieties belong to the monoecious group and the flower sex in this type is related to the stage of development of the plant. Normally, the first flower buds give rise to male flowers. Afterwards, female flowers emerge from the higher buds, and the frequency of these increases as the plant grows. At the very early stage of the flower, the primordia have bisexual initials. The sex of the flower is finally determined later and is related to the genetics of the plant, the position of the flower on the stem, influence of environment and endogenous hormone content. In the cucumber the node number index, i.e. the node where the first female flower emerges, is a genetically controlled factor.

Development of the male flower is favoured by long days and high temperatures, whereas short days and normal temperatures induce female flowers. The optimum conditions for induction of female flowers are low night temperatures and day temperatures of 17-24°C. During the warm days of early autumn and late spring, gynoecious varieties can induce male flowers which have to be pinched.

The incidence of male and female flowers is also related to the N and carbohydrate contents of the plant tissue. N fertilization promotes female flower development.

The application of external growth substances (NAA, IAA, 2-4D) induces female flowers even under long day and high temperature conditions. Gibberelins have a male sex inducing effect. The endogenous-content of gibberelin is higher in the monoecious than in the gynoecious plants. Ethephon favours female flower development from the youngest stages of growth.

A4. Fruit

The fruits are long, cylindrical, smooth or lightly thorny; the pulp is watery and has a low nutritive value. The most important long-fruited cultivars are parthenocarpic. These fruits become misshapen when the flowers are fertilized, because the seeds induce differences in growth of the pericarp.

A5. Climatic requirements

The cucumber is less temperature-demanding than the melon. The minimum germination temperature is around 12°C. The optimum is close to 30°C. Beyond 35°C, germination may be uncertain. Optimum air temperatures range from 18 to 20°C at night and from 20 to 25°C during the day. 27°C is the upper limit except where radiation is high. The soil temperature should be above 12°C.

Cucumbers require a high humidity; the recommended humidity ranges from 70 to 90%; In some regions the growers are forced to resort to sprinkler irrigation in order to achieve the required level.

The climatic conditions in Mediterranean plastic greenhouses do not fully meet the above-mentioned requirements. Low night temperatures limit plant development, as also do the wide thermal and humidity variations between night and day and the excessive temperatures in daytime, particularly during spring and autumn.

A6. Soil

The optimum soil pH is 6-7. When the organic matter content is high, the plant grows well at pH around 8. The soil must have good drainage, since the cucumber is sensitive to waterlogging.

B. Varieties

B1. Desirable characteristics

For protected cultivation the Gynoecious character is desirable, i.e., a plant with a 100% of female flowers. This has positive effects on fruit quality (since pollination is avoided), on earliness, and on labour economy.

Three cultivar groups can be found:

a. **Short fruits** (20-30 cm or more), monoecious; some well known cultivars are: Marketer, Ashley, Saticoy, Triumph, Astrea, Pioneer, Champion, Admirable, Robusta, Pacer, Cherokee, Palomar, Numbat, Victory, Dasher, Nory, Challenger, Quick Set, etc.

This fruit type is preferred by the Mediterranean consumer.

b. **Long fruits** (30 cm or more), parthenocarpic, good transport resistance.

There are three types of hybrids :

- **Monoecious**, with male and female flowers : Sporu, Green Spot, Bitspot, Cresta, Picador, etc.
- **Low number of male flowers**: Brillante, Princesa, Rocket, etc.
- **Gynoecious**, with only female flowers (the most widespread type at present) : Corona, Pepinex 69, Virgo A, Sandra, Daleva, Pandorex, Uniflora D-C, Monique, Fenspot, Farbio, Etc.

The whole group is exported to northern and central Europe markets since it fits their requirements, but it is not accepted by the Mediterranean consumer.

c. **Minicylindrical fruits** (less than 15 to 20 cm) : Pepita, Minisol, Delilah

N:B: In the south Mediterranean areas, the growers sometimes use "snake-melon(Cucumis melo var. flexuosus) which is a cucumber-type melon with rather good adaptation to temperature and water stress conditions. The most frequently used varieties are in North Africa : "Fakhouze", "Adjour" and "Bagdadi"

Pest and disease resistance

Nowadays cultivars have different degrees of disease resistance:

As an example, one may observe that :

- Asunta, Bella, Pepinova, Vetomil + Ashley, Cherokee, Dasher, Victory are resistant against Powdery Mildew and Downy Mildew;
- Brunex, Corona, Farbio, Farbiola, Pepinex are resistant to Cladosporium and Corynespora;
- Femscore and Mildana are resistant to all four of these diseases;
- Avir, Jason + Ashley, Challenger, Dasher, Victory are resistant to CMV.

As a rule, the choice of cucumber cvs - among those listed above and with the exception of local varieties - is specific to each country. Pepinex is the only one to be cultivated in a considerable number of regions : Spain, Greece, Turkey, Egypt, Tunisia, Morocco, ...

C. Cultural practices

C1. Growing period and cycle

Spain and some other Mediterranean countries concentrate on the production of long-fruited cucumbers in autumn and winter, when production in the importing countries of central and northern Europe is very low.

Planting time in cold PE greenhouses is in the second half of July or the first days of August. Harvesting extends from September till February, and is mainly concentrated in November, December and January. This autumn-winter cycle reduces the high yielding potential of the new hybrids, which could produce more and show their real potential if grown in a spring cycle.

The short-fruited cucumber, primarily grown for the home market, is sown in January or February for a spring harvesting season. It can be preceded by another short-cycle crop such as gladiolus, lettuce, snap beans, gourd, or egg-plant, heavily pruned at the end of harvesting in the summer, and again brought into production for an extra autumn yield.

When grown in the autumn cycle, cucumbers provide the opportunity to produce a previous spring crop such as melon, water-melon, tomato, green beans or pepper.

C2. Plant production

Three plant sources are available:

- direct seeding;
- transplants produced by the grower in blocks, peatpots, polystyrene trays, etc.;
- transplants produced by specialized companies or research (extension) stations.

When a grower chooses the direct seeding method during a cold season, he can save time by pre-germinating and it is in his interest to improve soil conditions with a view to facilitating emergence. The seeds are arranged on a surface kept humid by warm water (25°C to 30°C) until germination (1 to 5 days) at a temperature of about 25°C.

For a spring crop, seeding must take place about 40 days before transplanting, whilst for an autumn crop, some 25 to 30 days suffice. From 250 to 300 g of seeds are needed to plant 1 000 m^2 of greenhouse.

Many types of substrate can be used for cucumbers, as for any other crop, provided that they meet two conditions: high water-holding capacity and high porosity. (The composition can be based on peat mixtures : peat, sand and soil (1:1:1) in volume).

The general trend is to avoid pricking out in order to save labour.

The small plants developed from seedlings of the autumn cycle must be protected against high solar radiation (e.g. by shading) so that the levels of humidity in the substrate and in the air remain adequate.

C3. Soil preparation

The transplanting soil is prepared with 8 to 10 kg/m^2 of manure and also with mineral fertilizers. Nutrient uptake by a cucumber crop producing 100-120 T/ha is generally considered to be: 1.3 - 1.8 kg of N; 0.6 - 1.2 kg of P_2O_5; 2.5 - 3.3 kg of K_2O; 1 - 2 kg of CaO and 0.3 - 0.5 kg of MgO per ton of fruit. **Potassium** supply is specially important because of its role in the water economy, sugar transport, fruit quality and resistance to diseases. The soil is then ploughed and rotary-cultivated before being sterilized.

C4. Transplanting

Plants are transferred to the greenhouses when they have 8 to 10 leaves. Plant density should not exceed 2 plants per m^2 in order to avoid plant competition for light and aeration.

C5. Training and pruning

The cucumber is a climbing plant that needs a supporting system in order to grow vertically by means of its tendrils. Plastic or fibre nets are very useful for training. They hang down from wires stretched at a height of 1.50 to 2.00 m. The most adequate net is 20 x 20 cm wire.

A simpler system is that of single vertical strings attached to every plant as for tomato training, but this requires more labour.

Pruning operations can be summarized as follows :

Long-fruited cultivars : removal of side shoots and of the fruits on the main stem up to a height of 60-70 cm. Then removal of the side shoots up to 2 m; the fruits set on the main stem. Above 2 m, three branches are allowed to develop and are trained on the wire of the adjacent plant row and pruned according to the same criteria. All the misshapen fruits and old leaves are removed in order to improve aeration.

Short-fruited cultivars: the fruits and side shoots of the main stem are removed up to a height of 40 to 50 cm. There are then several courses of action :

a. The side shoots are pruned to 1 fruit and/or 1 leaf. The fruits on the main stem are removed.

b. The side shoots are pruned to 2 fruits and/or 2 leaves. The fruits on the main stem are removed.

c. The fruits on the main stem are allowed to develop. The side shoots are pruned to 1 fruit and 2 leaves.

d. The side shoots are pruned to 1 fruit and 2 leaves up to 1 m, then pruned to 2 fruits and 3 leaves up to 2 m. The fruits on the main stem are removed.

In each case the third order branches that may develop are pinched. Above 2 m the main stem is pinched; the side branches are allowed to grow and are pruned as described above.

C6. Fertilization

It is considered that **spring** and **autumn cycle** cucumber crops with a yield of 12 kg/m² remove from the soil

1.40 g	of N per kg fruit
0.80	of P_2O_5
2.60	of K_2O
0.40	of CaO
0.30	of MgO

Considering these figures and assuming that water is supplied by drip irrigation, the following can provide a soil of average nutrient content:

As from the 7th day after transplanting (per m² and per day) :

0.5 g of potassium nitrate
0.2 - 0.3 g of monoammonium phosphate
0.4 - 0.6 g of ammonium nitrate

As from the 45th day after transplanting (per m² and per day) :

1.0 - 1.5 g of potassium nitrate
0.2 - 0.3 g of monoammonium phosphate
0.2 - 0.3 g of ammonium nitrate
0.2 g of magnesium sulphate (once a week)

C7. Watering

The most frequently used irrigation systems are those that concentrate the water and the nutrients close to the plants. The cucumber is very sensitive to salinity. It may be advisable in some cases to leach the soil before planting in order to overcome this problem.

C8. Harvesting and marketing

The fruits are harvested when they become dark green, the ribs are less apparent, the apex rounded, and the diameter uniform.

Grading classifies the fruits into three groups : extra, I and II. The long fruits are plastic-sheated to improve conservation and transport quality. In this way the fruit keeps well in normal environmental conditions for 15 to 20 days, or in a cold-storage chamber for one month.

The fruit size required by European markets corresponds to 400-500 g per fruit, or 12 units per 5-kg box.

D. Major pests and diseases

Various **pests and diseases** represent a risk for the cucumber. From the youngest stage, Pythium spp. is a danger. Later on, fungi such as downy mildew (Pseudoperonospora cubensis), Botrytis cinerea, Alternaria alternata (Cucumerina tenuis). Fusarium oxysporum f. sp. cucumerinum, powdery mildew (Erysiphe spp.), Sphaerotheca fuliginea, Cladosporium cucumerinum, Corynespora spp. can threaten the crop. Some cultivars have been improved in order to resist or tolerate to varying degrees the second, third and last of the three diseases mentioned above.

A number of **viruses** are also pathogenic to the cucumber. Genetic resistance to some of these has been developed: C M V (Cucumber Mosaic Virus - Virus 1) which is propagated by aphids and through injuries, C G M V (Cucumber Green Mottle Virus - Virus 2).

Relevant **pests** are aphids, Trialeurodes vaporariorum (white fly), Lyriomiza spp. (leaf miner), Tetranychus urticae, and nematodes.

E. Economics

The yield that may be expected from an autumn cycle crop grown in a cold greenhouse ranges from 10 to 15 kg per m^2. A spring cycle in the same conditions can produce 18 to 25 kg per m^2.

The cucumber is a crop with a high labour requirement, due to the pruning and harvesting operations.

Of the total cost of production (labour, plant material, pesticides, fertilizers, etc) more than 50% are chargeable to labour, 20% to plant material and about 25% to agrochemicals and other items.

F. Major restraints

Limiting factors other than the climatic ones, already mentioned in former chapters, and common to other protected crops under Mediterranean conditions, are the progressive **salinization** of soils and water resources in some producing areas, and the very variable international market behaviour as far as demand and prices are concerned, which is difficult to foresee.

6.2.1.6 SUMMER SQUASH (Cucurbita pepo L.)

A. General description

The summer squash (courgette) is widespread in protected cultivation in the Mediterranean countries where the young fruits and sometimes the seedlings as well as the staminate flowers before anthesis are largely consumed. It is cultivated in plastic houses and also under low tunnels.

Some countries produce the Lagenaria siceraria (Mol.) Standl whose long fruits (up to 90-100 cm) are eaten boiled (called "zucchini" in Italy). But this is to be considered as a minor crop.

The varieties of C. pepo suitable for protected cultivation have short internodes, a semi-erect habit and no tendrils; they are thus known as bush squashes.

A1. Root

The root system is important; a strong taproot develops rapidly and may penetrate down to 150 cm in the soil; but the rootlet system is almost entirely located in the uppermost 60 cm.

The taproot produces lateral roots almost exclusively in the immediate vicinity of the apical zone (1 mm). As this portion can break easily on transplanting, which consequently would endanger the survival of the plantlets, direct sowing is to be preferred.

A2. Stem

The main axis of the plant is a real sympodium which in the bush varieties - contrary to the habit of other cucurbita species - grows slowly. As a result, the stem and the branches are rather short; the plant can be erect or crawl on the ground, but supports are never necessary.

A3. Other features

Other features to be considered for protected cultivation in Mediterranean areas are :

- plants of the bush varieties are normally monoecious, with unisexual flowers. For this reason, in greenhouses, the conditions for a satisfactory fruit set have to be created. Fortunately, the flowers are large and coloured, and relatively few in number;
- the very rapid growth of the fruits after fertilization of the ovules and the need for a timely removal of mature fruits to avoid competition with other flowers and young developing fruits.
- the rapid and important response of the plant to variations in temperature and humidity.

A4. Climatic requirements

With regard to temperature, the summer squash, like other cucurbitaceae, requires warm conditions for good growth, and even the bush varieties, though more tolerant, are not likely to resist frosts. Consequently in cool greenhouses, cultivation of the squash is limited to those areas where the risk of frost damage is absent.

On the other hand, C. pepo requires lower temperatures than other cucurbitaceae and other warm-season vegetables. A temperature of 20-25°C is optimal for germination, though 14-15°C suffices. At optimum temperatures, germination occurs within 4 days. The seeds are viable at 4°C for a long time.

The optimal values for growth range between 20 to 25°C during the day and 16 to 18°C at night; the soil temperature should be 15-20°C; the zero growth level is near 10°C; below 10°C the plant undergoes some damage which is more severe in the early phases (when necrosis can occur) or during the flowering period (drop of the youngest flowers). As a result, sowing during the coolest weeks of winter is to be avoided even in the Mediterranean area. Temperature is also the most important climatological factor for fruit-setting; at least 12-14°C are necessary for dehiscence of the anthers.

The summer squash tolerates neither very high temperatures (above 25°C good ventilation is necessary) nor low humidity levels. These conditions, which can occur in the unventilated plastic houses in the spring, can cause a loss of receptivity of the stigma and hamper the setting and early growth of the fruit.

High temperatures, high light intensity and long days promote the differentiation of pistillate flowers. A temperature of about 18°C and a relatively short day length favour the early formation of staminate flowers.

The conditions that follow winter sowing in the Mediterranean regions determine a cycle of about 90-120 days, whilst autumn cultivation allows harvesting to start 60-90 days after sowing.

B. Varieties

All the varieties suitable for protected cultivation are of the bush type; they can be cultivated without supports and at relatively reduced spacings.

The summer squash presents a wide range of varieties, differing in shape and colour. In protected cultivation, the long, regular in form, green or dark green, uniform or mottled fruits are preferred in the European part of the Mediterranean region. However, North Africa has a preference for the white, grey or light green cultivars.

The use of F_1 hybrids - Ambassador, Diamant, Diamond, Elite, Green Bush, President, Senator, are at present among the best known - is to be promoted in Mediterranean protected cultivation. These plants show a higher yield capacity than those of fixed varieties, a higher rate of growth, sometimes more earliness and - very important - some resistance or tolerance to viruses such as the cucumber virus (CV_1).

Generally, the types bearing dark fruits are likely to give more and better production. This behaviour would be related to a parthenocarpic characteristic, i.e. to an ability to set and develop fruits when the night temperature is low, the day length is short and the pollen viability is reduced; these conditions are frequent in the plastic houses of the Mediterranean area. Another advantage of such cultivars is their ability to produce fruits of regular form even if harvesting is delayed.

Among the light-coloured varieties "Greyzini" and "Clarita" seem to be the most interesting.

The choice or the creation of varieties can still help to improve the yield of the summer squash in protected cultivation. Besides, it seems worthwhile to look for varieties with growth habits that facilitate fruit picking and that are tolerant or resistant to Oidium. Indeed, the presence and the intensity of this disease is quite remarkable in the rather hot conditions of the Mediterranean area.

The squash cultivars listed below are cultivated in many countries:

- Diamond/Diamant : Spain, France, Italy, Tunisia, Algeria, Morocco;
- Elite : Spain, France, Italy, Turkey, Cyprus ...

C. Cultural practices

C1. Cultivation period

In the southernmost regions of the European area (above all in Italy and in Spain) the summer squash is a typical autumn-winter crop; an estimated 60% of the greenhouse production is harvested between October and March. Indeed, the squash is better suited to the environmental conditions of the winter season than the solanaceae or than other cucurbits.

Sowing is possible during a long period of the year. The cycles that start with autumn and produce in winter are preferable to those beginning at the end of winter or even later, since spring plants can be grown in the open after a short period under small tunnels. Therefore, the summer squash should be given the first position in the crop sequence and, as it has a relatively short productive cycle, it can be followed by one of the solanaceae (usually pepper or egg-plant). On the other hand, from late spring onwards the squash can encounter difficulties related to high temperatures and sometimes to low humidity (blossom-end rot of fruits, Oidium infections).

C2. Sowing

In view of the anatomy of the root (see above), the summer squash does not tolerate transplanting; direct sowing into the soil or into small containers is therefore more suitable. In this case, the plant can be moved to the field when 3 or 4 leaves have developed, and extreme care should be exercised not to damage the roots.

The sowing or planting is done in rows; the distance between rows should be about 1.00 - 1.20 m and between the plants about 60 cm.

The direct sowing method requires 4 to 5 kg of seeds per ha (as 2 or 3 seeds are to be placed in each hole to be sure to have one good plant in each hole after thinning, while sowing into small containers requires only 2 kg per ha.

Soils rich in humus, neutral or slightly alkaline and well drained are ideal for cultivation of summer squash. While lighter soils are preferable for early production, heavier ones produce higher yields. In the lightest soils, frequent in the Mediterranean regions, heavy applications of organic matter may be very useful. The rooting system requires good preparation of the physical characteristics of the soil. Various herbicides (Chloramben, Bensulide) can be used before sowing.

C3. Training and pruning

The summer squash does not require training nor pruning. However, the oldest leaves should be removed once their photosynthetic activity has ceased.

C4. Fertilization

The nutritional requirements of the summer squash for N and K_2O are rather high; an adequate content of nitrogen in the plant is necessary for the differentiation of pistillate flowers; on the contrary the K_2O is necessary to control the activity of the stomata and the water loss by transpiration and guttation.

In protected cultivation and for a yield of 40-50 t of fruits, about 170 kg of N, 70 kg of P_2O_5 and 390 kg of K_2O are removed per hectare. The absorption of nutrients is more intensive just after the first harvest.

C5. Irrigation

The summer squash is very sensitive to soil moisture, which should constantly be kept near to field capacity. Thus in spring, the sandy soils of the Mediterranean area need irrigating every three to four days. This is why drip irrigation and similar methods are advantageous. The volume of water required for the entire growing period can vary between 2 000 (drip irrigation during the winter period) and 9 000 m^3/ha (furrow irrigation during the spring period).

C6. Miscellaneous

The use of growth regulators to control the set and the growth of fruits does not at present seem a very useful practice. In fact, the action of these substances is unclear, at least when the temperatures are high; on the other hand in winter, when the temperatures are low, the problems which result from poor pollination and fruit set - as well as from insufficient fertilization - are less damaging for the squash than for the other species: the fruits can reach marketable size with few seeds or even with no seeds at all. Nevertheless, partial fructification can result in fruit deformation.

C7. Yield

The young fruits can be picked at various stages; some prefer a fruit weighing 100 g or less, sometimes with the corolla at the top of the peponid; others prefer more developed fruits (up to 200-300 g). Harvesting has to be repeated every second day to meet the demand for smaller fruits, but only every third or fourth day to supply the larger ones. The latter alternative gives better yields but the returns are comparable, since the smaller fruits sell at a higher price. The fruits are expected to keep well for a period of 2 to 3 weeks at 0-4°C and 90-95% of relative humidity.

D. Major pests and diseases

The main phytopathological problems of the squash can be :

- *Cladosporium cucumerinum*, which appears only during the winter season when the temperature is rather low: it can be controlled by the use of healthy seeds or by chemicals;
- *Oidium* fungi, especially *Sphaerotheca fuliginea* in protected cultivation, which appear in spring when the temperature rises; chemical control is effective;
- *Fusarium solani sp. cucurbitae*, *Schlerotinia sclerotiorum* and *Sclerotium rolfsii*; direct chemical control is rather difficult. In some microclimatic conditions (high humidity and temperatures) the presence of *Botrytis cinerea* on the stems, on the leaves and on the small fruits can be a problem.

Some viruses are present in the squash, the most dangerous being the *Cucumber Mosaic Virus* (CMV), which can only be controlled by indirect means (treated seeds, control of aphids). Genetic improvements promise results in the near future.

E. Economics

With regard to net return, the squash is comparable with solanaceous crops such as tomatoes and egg-plants.

For a general economic evaluation it is possible to point out that:

- the summer squash can be expected to yield about 50 t/ha, with variations ranging from 30 to 70 t depending on the cycles and technical conditions; in other words, the productivity is less than that of the tomato but similar to that of the pepper and egg-plant;
- the unit price for squash is, on average, lower than that for other crops;
- the unit cost of production is normally lower for the squash than for the pepper or the egg-plant, but higher than for the tomato;
- the unit cost can be apportioned as follows : 20% for materials; 30% for labour; 15% for other services (transport, sales, etc.).

The relative values of the cost can be summarized as follows:

Table 23 Relative values of the cost - per unit area (u.a.) and per unit product (u.p.) - of some vegetables in protected cultivation (reference : Sicily, year 1980)

Vegetables	Materials		Manpower		Other services		Allowances		Total	
	u.a.	u.p.	u.a.	u.p.	u.a.	u.p.	u.a.	u.p.	u.a.	u.p.
Squash	100	100	100	100	100	100	100	100	100	100
Tomato	148	84	179	101	173	78	120	68	152	86
Pepper	112	114	79	81	156	158	113	34	113	111
Egg-plant	141	126	171	164	170	162	124	119	149	143

F. Major restraints

The potential production of squash seems to be high and not fully exploited. The yield level is partially limited due to the insufficient quality of the planting materials and problems of crop management encountered during specific growing seasons.

With regard to the plant material, more success can be expected from the creation and cultivation of varieties more tolerant or resistant to pests (Oidium particularly) and which produce more parthenocarpic fruits.

With regard to production techniques, the major restraints seem to arise from problems of the physiological processes of growth in relation to variations in soil moisture and air humidity.

The low flexibility of the market may compromise to a certain extent the economic feasibility of squash in certain seasons and is therefore partially hampering the expansion of squash production under protected cultivation.

6.2.1.7 STRAWBERRY (Fragaria x ananassa Duch)

A. General description

The cultivation of the strawberry in greenhouses involves the large-fruited type, Fragaria x ananassa, rather than the small-fruited one, Fragaria vesca L.

In the Mediterranean region the crop is mainly located above latitude 40°N; while further south, it has recently appeared in protected cultivation and has since increased steadily. However, some problems need solving urgently.

The strawberry has a short rhizome that gives off long foliar petioles and fibrous roots. The latter grow downwards to 25-30 cm in the soil : 70% of them are located in the first 7 cm and 90% in the first 15 cm.

Long photo-periods and high temperatures promote vegetative growth and the formation of stolons (runners) which constitute a means of vegetative propagation of the plants.

The formation of flower buds on the contrary is induced under relatively short photo-periods when the plants have reached a sufficient stage of vegetative development; relatively low temperatures are also favourable but there may be differences according to variety. Intermediate day lengths and temperatures are favourable to "rosette" development.

There is an important interaction between day length and temperature : high temperatures have a lengthening effect - perceived by the plant - on the real day length. This explains why, in the south Mediterranean regions, runners can still be formed in October if transplanted into a greenhouse.

Vegetative growth ceases below 6-7°C.

Optimal environmental conditions for growth are around 10-13°C as night temperatures and 18-22°C as day temperatures.

A rather low air humidity level (around 60-70%) is preferred during the flowering and fruiting phases.

It may also be mentioned that the strawberry :

- prefers root media rich in organic matter with pH values of 5.5-6;
- has a high sensitivity to soil and water salinity over 1%;
- has a high total nutrient absorption which can be estimated at about 10-5-15 kg of N, P_2O_5 and K_2O respectively per ton of fruits.

B. Varieties

The classification of varieties according to photo-periodic and temperature requirements for production of flower buds is of great interest for protected cultivation.

A first group of varieties, the so-called "short-day cultivars" (or uniferae), induce their flowers if the day length is below a certain level (12-14 h) and if the temperature is not too high. The photo-period level varies between cultivars. Some varieties have a short inductive period while others have a longer one. It is also clear that in the south mediterranean regions (where the day length between 21 September and 21 March is longer than in the northern regions), cultivars with higher photo-periodic level have a longer inductive period than in the northern regions and, as a result, higher yields.

In regions with a mild winter climate, flower induction is continuous from late autumn to early spring. This is what happens to some varieties of Californian origin (Tioga, Aliso, Sequoia are the best known). But in regions where the temperature falls below 6-7°C, growth is interrupted during a more or less long period and flower induction re-starts at the end of the winter period.

Some varieties have a rather high photo-periodic level and cannot induce flowers during late autumn, winter or early Spring in the Mediterranean regions and for this reason are not of interest for protected cultivation in Mediterranean regions. These are sometimes classified as a second group of cultivars, the "long-day varieties".

The other group of varieties is less sensitive to photo-period. These varieties, recently created, are called day neutral. Their growth and flowering are controlled mainly by temperature; thus they could be very interesting for the more southern areas. Some varieties of this group, like "Pajaro" and "Douglas", have already shown good behaviour in the Mediterranean regions but further research has to be carried out to improve the characteristics of their fruits and the tolerance to some diseases.

The strawberry is a typical case : after facing a series of set-backs with European cultivars, the Mediterranean region has turned to the Californian one, Tioga, from which each country has tried to develop some cultivars better suited to its own needs.

Nowadays, the following cultivars are met in the countries listed next to them:

- Tioga : Portugal, France, Greece, Tunisia, Morocco,...;
- Aliso : France, Italy, Greece, Turkey, Cyprus, Lebanon, Tunisia..;
- Sequoia : Portugal, France, Italy, Greece, Lebanon, Tunisia...

C. Cultural practices

Under protected cultivation annual cropping is preferred, because the yields in the second year would be rather low and of unsatisfactory quality.

As in more northern regions, the annual crops are planted in the summer period, between June and September depending on the climatic conditions of the area, in order to have production in January in North Africa and in March-April or May in south Europe. Autumnal production in the south Mediterranean regions is not excluded, but the total yields are rather low.

In the Mediterranean regions the strawberry is cropped under large or small tunnels or plastic greenhouses; the cover must be set during the winter, after the plant has been exposed to cold conditions (around 7°C) to satisfy its chilling requirements. After this period, higher temperatures due to the cover ensure early vegetative growth, fruiting and improved fruit quality. The use of glasshouses is not convenient; they should be reserved for special growing systems (such as cultivation on artificial growth media, in hydroponic systems, etc.). Normally the strawberry is to be considered as a crop requiring protection only for part of its cycle, which is eight to ten months long in the Mediterranean area.

The main aspects of the cultivation are the following :

- **Soil preparation:** subsoiling should be limited to 50-60 cm in heavy soils and to 40-50 cm in lighter ones. Organic matter should be added. Ridges or furrows (80 cm wide and 40 cm apart) are utilized.
  Soil sterilization with methyl bromide or other chemicals is necessary for soils infected with Phytophthora cactorum.
  Ridges may be partially or totally mulched with black P.E. films 0.05-0.10 mm thick, mechanically after installation of the fertirrigation system; weed control (with trifluralin + lenacil) may be omitted, at least where total mulching with black P.E. is practised.

- **Plant propagation:** planting can be done between June and September, earlier in the northern and later in the southern areas. Cold storage of plants is advisable, otherwise good runners may not be ready for the earlier plantings. Early planting promotes "rosette" development early in autumn and flower induction over a longer period, which is favourable for higher yields.

  In the case of late transplanting of fresh runners, flower induction starts only in the late winter period and the harvest period is very short (a few weeks only).
  The plantlets should be bought on the market. Indeed, the preparation of good quality propagation material on the farm is difficult because of problems in the control of viruses and of Phytophthora cactorum.
  The plantlets are transplanted in rows 30 cm apart, with a distance of 15 cm between them in the row so as to give a density of 6 to 8 plants per m². Holes are torn in the PE films to receive the plantlets.

- **Fertilization:** the mineral fertilization to supply before transplanting in a "normal" soil, in addition to organic matter, is:
  40 kg of N, 80-120 kg of P_2O_5 and 200-250 kg of K_2O per ha. Side dressings are given at the end of the winter, when flowering begins, and continue until a few weeks before the first harvesting, at the rate of one fertirrigation per week to reach a total complement of 100-150 kg/ha of N and 100 kg/ha of K_2O. In alkaline soils, iron chelates as foliar sprays or applications of sulphur and iron sulphate to the soil before planting should be included in the programme.

- **Irrigation:** sprinkler irrigation may be used during the transplanting period to reduce the effects of high summer temperatures; drip irrigation is advisable after flowering, in order to avoid problems of fruit-set and disease.

  The availability of water in the soil must be high; if it is reduced, the absorption of P_2O_5 and K_2O is severely hampered.

  The total water requirement per ha ranges from 3 000 to 9 000 m³, and the rooting system is such that it requires frequent but moderate irrigation of the crop (at least every 2 or 3 days).

- **Other techniques:** an aspect specific to protected cultivation is the period of covering of the plants. Covering usually starts in November in the southernmost regions and in January in the northernmost ones, depending also on the low temperature requirements of the varieties grown. Other practices are:

- removal of the first flowers and runners after transplanting to obtain stronger rosettes;

- the introduction of bees to promote fruit-setting;

- and sometimes the use of very low concentrations of gibberellic acid to hasten the growth after the winter season (too high a concentration results in flower abortion);

- **Harvest**: this is progressive and expensive (from 25% to 35% of the total costs).
  The fruits must be hand-picked at least every three to four days at the proper stage of maturity. The harvest can be delayed in the varieties with more firm flesh of the berries.
  The fruits should be packed as they are harvested because handling results in poor keeping quality, and then preserved immediately at a temperature of 5-6°C (vacuum or hydrocooling system). They can keep for a week at 0°C and 95% of humidity.

D. Major pests and diseases

The main problems are caused by Botrytis cinerea and Phytophthora cactorum, which attack the propagating material and the floral and fruit structures. Other fungi often present in protected cultivation are Sphaerotheca macularis (mildew), which infects the whole plant, and Mycosphaerella fragariae which infects the leaves.

Some viruses are of importance: "Mottle", "Mild Yellow Edge", "Crinkle" and "Leaf Curl" viruses.

Aphids and red spider must be carefully controlled.

E. Economics

The yield potential of the plant is very high, but production is variable depending on the thermo- and photo-periodic conditions and the sensitivity of the different varieties to these conditions. The usual average yield is about 20 tons per hectare, but double this figure can sometimes be obtained.

Very interesting prospects for more stable yields and for a further spread of the crop can be based on the availability of new varieties, less responsive to temperature and light.

The cost in Italy can be estimated at about one dollar per kilogram of production. this is about 60% higher than the cost for open air cultivation.

The main items are:

- planting (materials and labour) : between 25 and 30%
- cultivation : 20%
- harvest : 20%
- capital amortisation : 25%

6.2.1.8 LETTUCE (Lactuca sativa L.)

A. General description

This "salad" crop is very interesting for protected cultivation in the northern Mediterranean areas owing to its short cropping cycle and its low temperature requirements.

Seed germination takes 3 days at 15-20°C and 15 days at 5°C. Temperatures above 25°C reduce germination, which falls to 12% at 30°C. As a consequence, nurseries should be shaded when the weather is warm and sunny in order to lower the soil temperature. The seed dormancy period can be rather long and is interrupted by exposing the seeds to low temperatures (2°C for 48 hours).

The lettuce resists light frosts, but temperatures above 30°C may be harmful.

Head formation depends on the balance between light intensity and temperature : low light and high night temperatures may inhibit head formation in winter or cause the head to become too coarse : this phenomenon is particularly observed when using "radiant mulching", which brings warmed water near to the heads.

Bolting is the result of a combination of high temperatures and long days, and is more frequent in spring-summer than in autumn-winter time in southern Europe. There are many bolting-resistant cultivars.

B. Varieties

The two main types of lettuce cultivated in the Mediterranean region are:

- the **"roman type"**, with long upright leaves and without a head, grown in the open in many Mediterranean countries;
- the **"head type"**, with curled leaves forming a "ball". This is the type most widely grown and the consistency of the leaves determines the category:
  - the crispy head cultivars, with harder leaves, such as "Iceberg", "Great Lakes", "Batavia", etc., mainly grown in the USA;
  - and the butterhead cultivars, round with soft leaves, such as "Trocadero", "Verpia", "Ravel", "Estiva", etc., mainly grown in Europe.

Various factors influence the choice of cultivar :

- market preferences : crispy or butterhead, dark or light green leaves, size of the plant, etc.
- the growing period : in summer, cultivars must be resistant to bolting and to high temperatures; in winter, they must be adapted to low light and low temperature conditions. No cultivars should be expected to perform well all the year round;
- resistance to diseases, especially to Bremia.

C. Cultural practices

Although the lettuce is easier to grow than other vegetable crops such as the tomato or the melon, it requires precision to get a uniform crop that can be picked in one harvest.

Transplanting is preferred to direct seeding. The plants can be transplanted bare-rooted, but then the cropping cycle is more extended and the plants are less uniform than with soil blocks (pots, pressed blocks, trays, etc.). The price of blocks varies with the size but the smaller ones expose plants to drought and therefore irrigation in the nursery requires constant care. Pelleted seeds facilitate sowing and increase the uniformity of emergence.

Planting distances are important and mainly depend on the size of plants. High plant densities increase the yield per m^2 but reduce the size of plants and favour the development of fungal diseases. If the plants become too crowded, humidity increases owing to low air circulation. The usual density is 12 to 20 plants/m^2.

A lettuce crop yielding 4 kg/m^2 removes 100 kg of N; 50 kg of P_2O_5 and 250 kg of K_2O per ha from the soil. Excess of N is harmful because it delays formation of the head and may bring the N-content of leaves up to a dangerous level. In winter, the K/N ratio should be higher than in summer in order to compensate for the low light conditions.

The lettuce is **very sensitive to soil salinity**, therefore fertilizers must be applied in small quantities to avoid increasing the salt-content of the soil. Salinity is also controlled by irrigation. Soil leaching is recommended before planting. When irrigation is insufficient, as often happens in the corners of the greenhouse owing to poor water distribution by sprinklers, the plants may show symptoms of excess salinity : dark green leaves, restricted growth and flat plants without heads.

The **cropping cycle** ranges from 60 to 80 days depending on the earliness of the cultivar and the climate. The yield depends on the size of the plants at picking time and on the number of plants /m^2. A good crop may produce 3 to 4 kg/m^2.

D. Major pests and diseases

The following fungal diseases pose the greatest threat:

Bremia: when the leaves are attacked, they become covered with a white mycelium and rot completely. Some cultivars have been developed to resist several races of bremia. The most efficient fungicides are metalaxyl, curzate, prothiocarbe and some other anti-mildew formulations.

Botrytis: this is the common grey rot of the leaves. Suitable fungicides are iprodiona, vinchlozina, etc.

Sclerotinia: the crop becomes infected from the soil. The white mycelium attacks the stem. The plant first becomes etiolated and suddenly dies. Sterilization of the soil is important. Moreover, the fungicides used to destroy Botrytis are also useful against Sclerotinia.

These three diseases generally appear when moisture is high. Therefore, ventilation, good management of sprinkler irrigation and the use of plastic mulching to avoid direct contact of plants with the soil, all help to lower the risks of disease. Fungicides should be kept strictly for secondary control in order to limit the amount of residues in the leaves after repeated applications. Early applications (in nurseries) are to be preferred because they offer protection right from the start, controlling the primary infections, and are likely to be eliminated before picking time. Powder formulations give better results than liquid ones.

Tipburn is a frequent physiological disorder. The plants show necrosis on the margin of the leaves. It is due to an imbalance between water absorption and transpiration associated with calcium deficiency or too low a Ca/K ratio.

E. Major restraints

A lettuce crop returns less profit per m² than any other protected vegetable crop, but its short growing cycle and the low production cost makes it profitable in many situations, principally in Mediterranean Europe. It is not usual to produce lettuce all the year round in the Mediterranean region owing to competition from open air production and to the high temperature that favours the area most of the time. Lettuce is grown mainly in regions experiencing cooler weather in winter and in the vicinity of urban centres in order to keep transport costs within reasonable limits.

6.2.1.9 SNAP (FRENCH) BEAN (Phaseolus vulgaris L.)

A. General description

A1. Root, Stem

The snap bean is an annual leguminous plant with a shallow, branching root system. Some cultivars, the **climbing** snap beans, have a creeping stem that can reach 2 to 3 m long; other varieties, the **dwarf** beans, have an erect stem than reaches 40 cm.

A2. Flower

The axillary flowers develop in trusses with 4 to 8 flowers.

A3. Climate

Beans are self-pollinated, but fruit and seed develoment can be affected by climate. Low temperatures in wintertime may induce poor pollen production, little pollination and thus, bad seed setting, the pods becoming curled. The growth of the ovary wall depends on the presence of seeds. The **temperature** requirements of the bean are as follows:

optimum germination temperature	15-25°C
minimum biological temperature	10-12°C
optimum vegetative development temperature	18-30°C
optimum temperature for flowering	15-25°C

Wide thermal variations can affect the quality of the pods. Extremely high temperatures as the pods approach harvesting speed up seed and fibre development, especially when the soil moisture is low. Dwarf cultivars are less temperature-demanding than climbing ones.

The air humidity should ideally approach or even equal 60-75%.

A4. Soil

The snap bean can be grown on many different soils, although it prefers light soils and dislikes the heavy ones that are poorly drained. Soils with a high calcium content yield lower quality pods with more fibre development.

It is one of the most sensitive plants to soil **salinity**.

B. Varieties

B1. Desirable characteristics

Earliness, high yield, low fibre-content, slow seed development and disease resistances (Anthracnose, mosaic, bacterial diseases) are desirable characters for protected cultivation, as well as the shape of the pods depending on the specific market (flat or cylindrical pods).

The cultivars are **classified** according to their growth habit:

- the **dwarf** snap beans that need no training;
- the **climbing** cultivars that, supported on vertical strings, are the most widely cultivated ones under protection.

The main varieties found in greenhouses are the traditional ones, and to a lesser extent some foreign cultivars.

- climbing cultivars : Valenciana, Buenos-Aires, Garrafal Oro, Satsuma, Helda, Zondra, Romore;
- dwarf cultivars : Garrafal Rabona, Mocha Blanca, Kora, Contender, Eagle, Strike, Amilcar ...

C. Cultural practices

C1. Growing period and cycle

There are two different cycles for greenhouse growing:

a. sowing in **December and January** for spring production from March to July. This may be preceded by peppers, short-cycle tomatoes, an autumn cucumber crop, or lettuce;

b. sowing in **September and October** for harvesting from December to February. This may be followed by water-melon and melon in the southern regions and also by squash, spring cucumbers, tomatoes, or peppers in the northern areas.

As for growing in **low tunnels** or **with mulches**, depending on the latitude and the microclimate of the region, sowing is done in February and March for harvesting from May to August.

The harvest starts 55 to 85 days after sowing and lasts 40 to 50 days for the dwarf varieties, while for the climbing varieties, harvesting starts 65 to 95 days after sowing and lasts 60 to 90 days. It generally takes 7 to 12 days from anthesis till pod harvesting.

C2. Plant density

Direct sowing is practised either in holes or in rows for the dwarf varieties, and always in holes for the climbing ones. The distance between plants varies:

climbing varieties: 1.00 x 0.33 m .... 3 plants per hole
1.00 x 0.50 m .... 4-5 plants per hole
1.25 (path) x 0.80 (row) x 0.70 (plants)
.... 5-7 plants per hole

dwarf varieties: (if sown in rows, the distance between the plants in the line is about 5 cm)
0.60 x 0.40 m .... 5-7 plants per hole

When the plants are some 15 cm tall, they need ridging up.

C3. Training and pruning

The dwarf cultivars are not pruned at all, while the side branches and the subsequent order branches of the climbing varieties are pinched on the 3rd or 4th node. Some leaves are removed in order to improve air circulation.

Vertical strings support the climbing plants in protected cultivation.

C4. Fertilization

As a general criterion to bear in mind, the N supply must be limited in the early stages in order to avoid excessive growth. On the other hand, "slow release" fertilizers are not advisable, since the snap bean cycle is a short one. For the same reason, N is incorporated before sowing and a supplementary dressing is given. Assuming a crop yield of from 3 to 5 kg per m², the amounts recommended per ha are:

200 - 270 kg of N	300 - 400 kg of K_2O
150 - 220 kg of P_2O_5	50 - 90 kg of MgO

The crop is very sensitive to deficiency of several trace elements (Cu, Mn, Zn), which explains the positive reaction to complete fertilization. It is also very sensitive to excess B and NaCl.

C5. Irrigation

Irrigation must be abundant before sowing and then suspended until the plants are about 15 cm tall. The bean is very sensitive to moisture excess, and water supply must, therefore, be limited during the young stage. The water requirements increase after flowering and the total amount for a spring crop is between 3 000 and 4 000 m³ per ha.

Beans are rather sensitive to saline water, especially if it contains Cl^- ions. A content of 250 mg/l of Cl reduces yield by 20-25%.

C6. Harvesting and marketing

The pods are picked green, before the seeds enlarge. Harvests must be repeated every 4 to 6 days to ensure good quality and uniform fruits. Harvesting the pods at an early stage of development does not reduce total yield, but stimulates flowering and gives better prices. One man can harvest some 70 kg of pods per day.

The normal pods fall into category No. 1 and the curved ones with enlarged seeds into No. 2.

For the local market, the vegetables are packed into 25-kg bags or in 8 to 10-kg wooden boxes, while 5 to 10-kg trays are preferred for export. The pods keep well at 2-4°C and 85% humidity.

C7. Yield

Dwarf varieties grown in favourable conditions can yield 1.5 to 3.0 kg per m², and an autumn-winter cycle can produce 1 - 1.5 kg per m² when grown in cold greenhouses.

Climbing cultivars cultivated in the spring yield 2 to 4 kg per m²; these figures decrease to 1.5 - 2.0 kg per m² when grown in autumn-winter.

D. Major pests and diseases

Aphid control is important in order to avoid virus infection. Other significant pests and diseases are white fly (Trialeurodes vaporariorum), spider mite (Tetranychus urticae), anthracnose (Colletotrichum lindemuthianum), Botrytis cinerea, halo blight (Pseudomonas phaseolicola), common bacterial blight (Xanthomonas phaseoli), Common Bean mosaic (PV1), Yellow Bean mosaic (PV2).

E. Economics

The approximate cost distribution for an early spring production cycle is as follows: seeds 3%, agrochemicals (fertilizers and pesticides) 14%; labour 74%; other costs (water, plastic film, cultivation, etc.) 9%.

F. Major restraints

The factors that hamper the extension of the crop are:

a. the tremendous **amount** of **labour** that harvesting requires; this weighs heavily in the economic balance. For this reason the crop is cultivated in association with a main crop such as the tomato, pepper or watermelon in some Mediterranean regions. The development of cultivars allowing mechanical "once-over" harvesting would, therefore, be appreciated;

b. the high **sensitivity to saline conditions** in soil or water.

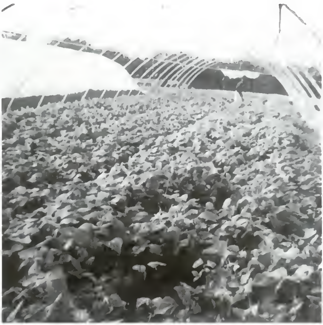

Fig. 96: Catch cropping in autumn before covering with plastic (Tunisia)

6.2.1.10 WATERMELON (Citrullus lanatus Mansfed = C. vulgaris L. Schrad)

A. General description

The various vernacular names given to the watermelon in ancient literature testify that this crop has been known in the Mediterranean region for a long time. The Mediterranean climate undoubtedly looks the most suitable one to meet its specific heat and light requirements.

The past few years have seen the passage from the traditional system of open-air production to the system of protected cultivation, and this move has been in constant evolution. The principal aim is to develop spring harvesting as an alternative to the summer crop. So far, advancement of cropping has been achieved mainly through cultivation in low tunnels used to provide temporary protection to the plant in its early stages of life. The floral biology and the growth habit of this plant remain the major obstacles to the development of greenhouse cultivation as they hinder some cultural practices and make training difficult.

The watermelon is an annual shallow-rooted plant, with long, vigorous runners; the leaves are ovate to obovate and deeply pinnatifid; the tendrils are branched. The flowers, yellow with green sepals and corolla deeply parted, are located singly in the leaf axil. The plant is monoecious and andromonoecious and the flowering sequence starts with staminate flowers at the first 3 to 8 nodes according to the environmental conditions. Perfect or pistillate flowers appear between the 8th and the 12th node; the ratio between staminate and pistillate or perfect flowers is controlled by plant genotype.

The fruits are large - from 2 to more than 15 kg - round or oblong; green or striped externally, and the flesh is red and occasionally yellow; the seeds are of various sizes (8 to 25 per gram) and colours.

The requirements of the plant can be summed up as follows:

a. **Climate**: the watermelon requires a long, frost-free growing season with high temperatures. Its thermal requirements are:

   - germination: 25-28°C, with a minimum of 15-16°C and a maximum of 40°C
   - growth: 21-26°C during the day and 15-18°C during the night;
   - temperatures: growth is considerably delayed below 17°C: rather low or fairly high temperatures (above 32°C) promote the production of male flowers at the expense of the female or perfect ones.

The plant is not highly sensitive to extremes of air humidity but prefers a level of 70 to 80%.

Furthermore, the watermelon requires maximum levels of light intensity in order to reach full photosynthetic activity : the solar radiation must be at least 1.1 cal/cm²/min and therefore, shading conditions are to be avoided. The daylength does not affect the growth pattern significantly but female sexual expression is promoted by short days (8 hrs) rather than by long ones (16 hrs).

b. **Soil**: the optimum pH values range between 5.5 and 6.5. Ligher soils, which warm up rapidly in spring, hasten maturity. Reasonable yields are obtained in heavier soils provided that watering is properly controlled and any "free water" is drained rapidly after irrigation.

A high humus content is essential.

c. **nutrients**: the only figures that can be given are for open-air crops, where it is estimated that the watermelon requires 1.7 kg of N, 1.3 kg of P_2O_5 and 2.7 kg of K_2O per ton of yield. The values for protected cultivation are no doubt higher, but no specific data are available so far.

B. Varieties

There exists a wide range of cultivars that vary in shape, size and external colour but, in protected cultivation, preference is given to varieties producing relatively small-fruited varieties (2 to 10 kg). Such varieties enjoy a ready sale on the out-of-season market.

As a rule, these varieties are early ones and the first fruits may become mature 70 to 80 days after sowing, providing that the environmental conditions are optimum. This period may extend to 100-120 days in out-of-season conditions.

The most widely known variety in protected cultivation is the old-established Sugar Baby, producing round dark green fruit, and generally considered as the earliest of all. Sugar Baby is found in Portugal, Spain, Italy, Greece, Cyprus, Tunisia and Morocco. Other varieties and some F_1 hybrids are also cultivated : Crimson Sweet (cultivated in Italy, Greece, Cyprus, Lebanon and Tunisia), Fabiola, Sweet Meat, Sweet Ball, Miyako and sometimes (see Tunisia) the large-fruited varieties Charleston Gray and Royal Charleston.

Future research should be oriented towards developing varieties with improved tolerance or resistance to the more important diseases (resistance is currently limited to Fusarium and Alternaria spp., and this only in a few varieties). Seedless triploid hybrids (with only aborted seeds) may also prove to be of interest.

C. Cultural practices

C1. Cultivation period

Owing to climatic requirements with regard to temperature as well as to light, autumn sowing with a view to obtaining production in winter is unthinkable even in the Mediterranean region. All cultivation cycles, including those of the earliest types, are initiated between December and May so as to harvest in spring and summer. Tunisian growers start sowing their early species in the greenhouse during December, and harvesting takes place between March and the end of May.

Under low tunnels, winter sowings lead to April-to-July harvesting.

The cropping sequence varies according to whether cultivation is practised in a greenhouse - in which case the watermelon follows a winter crop (lettuce, beans) - or under tunnels, where it can precede or follow open-air crops other than vegetables (cereals, ...)

C2. Sowing

The watermelon does not tolerate bare-rooted transplantation and, therefore, direct sowing or sowing in pots, in hotbeds or greenhouses is essential.

In the case of direct sowing, transparent plastic mulching is useful to hasten germination. Holes are torn in the film immediately after emergence in order to let each seedling through.

Pre-germinated seeds can be used at the rate of 1-2 kg per ha, according to the unit weight.

The plants are spaced 100 to 150 cm apart in rows 150 to 200 cm apart.

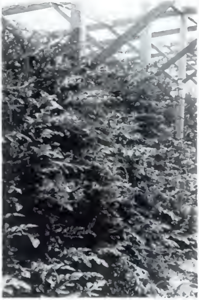

Fig. 97: Watermelon cultivation in a cold greenhouse in Sicily (La Malfa)

C3. Soil preparation

The root system is relatively shallow but quite voluminous and more often than not overgrows the runners laterally as indeed the growth is rapid and extensive in the upper 30 to 40 cm of the soil profile. The soil should therefore be dug thoroughly and deeply (at least 40 to 50 cm) as early as possible, and manure can be worked in.

Every precaution should be exercised in the preparation of the soil so as to avoid any later contact of the vines and of the fruits with water during irrigation.

Immediately prior to sowing, fertilizers should be applied at the rate of 100 kg of nitrogen, 150-200 kg of P_2O_5 and an equal quantity of K_2O per ha.

C4. Cultivation and weeding

Additional side dressings of nitrogen (about 100 kg/ha) prove necessary at an early stage of growth.

Weeds can be controlled mechanically by continuous cultivation of the soil or can be killed with various chemicals such as **butralin** and **chlorthaldimethyl** applied before sowing or **trifluralin** and **alanap** 3 as post emergence applications after the development of the runners (see § 5.5).

C5. Irrigation

The irrigation system must be arranged so as to provide a constant water supply. Variations in the available water level in the soil have a damaging effect on the growth and on the quality of the fruits.

The plants require larger volumes of water from the development of the vines up to fruit-setting. Furthermore, it should be remembered that the growth of the fruits follows a sinusoidal curve and that they reach 50% of their weight in the first fortnight after setting.

C6. Other techniques

Additional techniques required include pruning and training, control of fruit-setting, removal of the covering (when grown in tunnels) and correct ventilation (in the case of cultivation in greenhouses).

Pruning, under tunnels, consists in topping the main stem after the fourth leaf in order to promote branching. The lateral branches may be topped similarly.

Vertical training is an advantageous system in greenhouses to increase the number of plants per m² and to allow certain cultural practices to be carried out. However, plant and fruit support is sometimes a difficult problem to solve; plastic nets properly arranged seem a useful solution.

Fruit-setting in protected cultivation requires the utilization of bees or of mechanical processes (fairly easy, because of the size of the flowers).

D. Potential yield

In protected cultivation and especially in greenhouses, the production potential of the crop is often limited; this for several reasons:

- the growth can be insufficient;
- the fruit-setting can be difficult;
- the environmental factors can be unfavourable;
- the June harvests coincide with open-air production, and
- the early cultivars chosen are small-fruited types.

The earliest crops under low tunnels yield 3.5 to 5 kg/m^2 (i.e. an average of 2 fruits per plant), while in greenhouses the yield can reach 7 to 8 kg/m^2. Better yields can reasonably be expected from vertically trained crops.

E. Pests and diseases

Various soil-borne fungi such as the Pythium spp and Rhizoctonia solani cause plantlets to decay. Seeds treated with protective fungicides, shallow sowing and planting, and a relatively high soil temperature are some of the factors that may help to avoid - or at least to reduce - damage.

Wilt is the most destructive disease. It is caused by various species of Fusarium oxysporum var niveum which penetrate into the plant through the roots and attack the plant at different stages of growth. The first symptoms appear at the tip of the runners, the plant wilts rapidly and eventually dies. This fungus thrives at high temperatures and can survive in the soil for several years. The disease can be controlled indirectly by means of a system of long crop rotations, the use of disease-free soils and of resistant or tolerant varieties.

Other diseases that can be troublesome are : Anthracnose, caused by Colletrotrichum lagenarium, Oidium spp., powdery mildew caused by Erysiphe cichoracearum...

Viruses as well as nematodes (Meloidogyne spp.) and aphids are also a constant menace.

Last but not least, attention has to be drawn to the possible necrosis of the apical portion of the developing fruit. It seems favoured by irregular watering, the use of cold water and difficulty in translocating calcium from the stem to the fruits.

F. Economic aspects

The value of the produce is more closely related to the earliness of harvesting than for any other crop. All the fruits available before June find a ready sale and, as a result, are sure to return a profit.

The production costs are lower for watermelon than for the majority of the other vegetables. An estimated 400 to 700 hours of labour are needed per ha, and this represents 40 to 50% of the total production costs.

G. Major restraints

The main impediment is undoubtedly the lack of know-how involved in improving the crop in protected cultivation.

In addition, many problems still await solutions, e.g. training, pollination, irrigation, fertilization, apical necrosis of the fruit, as well as the direct or indirect control of numerous pests and diseases.

6.2.2 ORNAMENTALS

6.2.2.1 CARNATION (Dianthus caryophyllus)

A. General description

The carnation is a semi-hardwood plant producing many upright stems at the top of which the flowers appear. A typical flowering stem develops 15 to 18 nodes with two opposite leaves at each node from where the new shoots emerge. The lower nodes produce vegetative shoots but the upper ones give small shoots with flower buds in addition to terminal flowers. The higher the number of shoots and the shorter the time between flower harvest and the development of new shoots, the higher the yield. In good climatic conditions, one carnation plant may produce up to 10-15 flowers.

Light is the environmental factor that most influences the rate of growth and flowering throughout the year. Photo-period and light intensity influence stem length, branching and growth rate. Short days induce longer stems, larger flowers and more lateral shoots. Long days promote shorter stems and less lateral shoots. But, the higher the light intensity, the faster the plant growth. This crop is unsuitable for regions that frequently have light intensities below 20 000 lux. in wintertime.

The time between the stage at which the buds are 7 mm in diameter and harvesting greatly depends on the light intensity. It ranges from about 25 days in summer to 50 days in winter for plants submitted to a minimum temperature of 10°C.

The temperature requirements for vegetative growth and flowering are quite low : minimum 8°C, maximum 25°C. The carnation is frost-resistant down to -4°C, though negative temperatures have some adverse effects on the plant : they may kill the flowers and induce colour changes in the petals. As a result, the carnation is not suitable for regions where the summer is hot.

Wide differences between night and day temperatures may cause calyx splitting owing to the formation of a high number of petals which the calyx cannot contain. This often occurs in spring when the nights are rather cool and the days quite bright. The value of the flowers is reduced.

B. Varieties

Carnations intended for the cut-flower market belong to the species Dianthus caryophyllus, while other Dianthus spp. are used as bedding and pot plants.

The first perpetual flowering carnation cultivars appeared about one hundred years ago, and from them two main types have been selected :

- the **Mediterranean cultivars**, with laciniate calyx, large flowers, shorter internodes and considerable resistance to low temperatures;
- the **American cultivars**, having a more regular corolla, longer internodes and smaller flowers but with rather greater sensitivity to low temperatures.

At present, some Mediterranean cultivars are still grown in the south of France, though all but a few carnations around the world are American or hybrids of the two types created to combine the advantages of both forms.

According to the number of flowers per stem, the cultivars are grouped as **standard**, having only one large flower per stem, and **spray** or **miniature**, producing several small flowers arising from the upper nodes, the terminal flower being removed.

The most widely spread cultivars are the Sim carnations, mainly the red, pink and white colours. There is a large demand for white carnations, as they match well with various colours such as blue, green or brown.

For many years, breeders have focussed their attention on the size, form and colour of the flower as well as on the vigour or productivity of the plants of Sim cultivars but nowadays the danger of Fusarium (cf. Section D) makes it essential to develop resistance to this disease.

Few Mediterranean countries grow carnations. Where they have been adopted, the "Sim" cultivars are those most frequently met, as in Portugal, Spain, France, Cyprus, Morocco... "Praline" is grown in Spain, Italy and Greece.

C. Cultural practices

Propagation is done by stem cuttings, generally in specialized nurseries to avoid contamination with viruses and fungi but also because of the need for special misting equipment and sterilized beds.

Rooted cuttings are planted in beds about 1 m wide. Planting dates depend on the time at which picking is scheduled to start. It takes 110 days in summer and 150 days in winter for plants to reach peak flowering. As the prices are usually higher in winter, most plantings are done in May/June to start harvesting in September/October. When this programme is followed, the greenhouses are only covered in September so that the carnations remain in the open throughout the summer, enjoying more favourable temperature conditions.

The higher the plant density, the greater the yield per m² but the lower the production of flowers per plant. Over-crowded plantings cause ventilation problems and the investment/m² becomes too high. The usual plant densities range from 20 to 30 plants/m².

The number of flowers per plant depends on the number of stems. The pinching of young shoots to stimulate branching increases the number of flowers but delays peak flowering. Planting may be followed by various pinching operations:

- **single pinch** - it is a requisite; the main stem is pinched above the second pair of leaves.
- **one and a half pinch** - single pinch as above, followed later on by the pinching of half the shoots resulting from the first one.
  This system reduces the number of flowers in the first crop but provides a steady production without peaks and troughs, at least in the first year of production;
- **double pinching** - single pinch followed by pinching of all the resulting shoots. This is not recommended because it considerably

delays the first crop and makes it too heavy owing to the numerous secondary stems.

Plants need training to keep the secondary stems in an upright position. This is generally provided by 3 to 5 layers of netting of 10 to 20-cm mesh.

Standard cultivars need disbudding; indeed, all the flower buds appearing from the six nodes below the terminal bud have to be removed. The best time to do this is when the terminal bud is about 15 mm in diameter. If disbudding is done too late, competition reduces the size of the terminal flower. Spray cultivars do not need disbudding; only the terminal flower is removed to allow the lateral flowers to develop.

The height at which flowers are cut has an incidence on crop timing as well as on the number of flowers produced. In summer, branching being more reduced, the flowers should be cut higher on the stem so as to increase the number of secondary shoots, and consequently, the winter production, whilst, in winter, flowers should be cut lower on the stem. Usually, they are cut above the 2nd or 4th pair of leaves.

The carnation can be left in the field to produce over a period of 2 years or be removed after the first season. If kept for a second year, the plants should be cut late in spring so as to eliminate mid-summer production when the demand is meagre and the prices are not attractive. Electric hedge trimmers can be used to cut the plants 20 to 30 cm above ground level. The operation must be terminated by early June, otherwise the plants will take too long to recover and the first peak flowering will come after October.

D. Major pests and diseases

The most threatening disease for the whole plant is fusarium wilt (Fusarium oxysporum spp. dianthi). It is sytemic, the fungus invading the plant from an infected soil, causing foliage yellowing and plant wilting. The spores are very resistant to the usual soil fumigants so that infected soils become unsuitable for this flower crop. The first resistant cultivars are appearing and this serious problem should be overcome within a few years.

The most common foliar diseases are alternaria leaf spot (Alternaria dianthi), rust (Uromyces caryophyllinus) and gray mold (Botrytis cinerea), which also affect the flower buds. These fungi are favoured by high moisture conditions. Adequate ventilation is therefore the surest way to reduce the danger. This, and the low requirements of the carnation with regard to temperature, are the reasons why greenhouses with permanent ventilation are often used for this crop.

E. Major restraints

The carnation requires a great amount of labour, disbudding and harvesting representing about three quarters of the total labour. This is the reason why countries with expensive labour are shifting from standard to spray cultivars that do not need disbudding. For the same reason, small farms using family labour are more profitable than bigger ones.

The carnation is very well adapted to the Mediterranean regions favoured by sunshine and fairly warm temperatures in winter. Other very appropriate regions are the equatorial zones situated above 2 600 m. Countries such as Kenya, Colombia and Ecuador export huge amounts of flowers to the European and US markets.

The major restraints on carnation development in the Mediterranean countries are the cost and availability of labour, the transition to other flower crops, the competition from equatorial countries and the infection of soils by fusarium.

Digitized Theses

6.2.2.2 ROSE (Rosa L.)

A. General description

The rose has been grown for centuries, and this explains why there are now so many varieties of botanical species of the genus Rosa. The plants belonging to this genus are perennial, shrubby or climbing, with woody stems and, originally, with pentamerous flowers.

A1. Climate

The rose is relatively tolerant to low temperatures. For most varieties, the temperature requirements may be defined as follows: lethal minimum, below 0°C, biological minimum, from 8 to 12°C; biological maximum, from 30 to 32°C. A certain thermal differential between day and night is a requisite (thermoperiodism). Furthermore, the night temperature determines the length of flower stalk. Indeed, low temperatures retard the growth of the stalk, advance the differentiation of the terminal flower bud and cause the flower stem to remain too short. Unheated roses produce longer stems in autumn than in spring owing to differences in hight temperature. The night temperatures also define the period of time between pruning and harvesting. High temperatures are also required in forced cultivation during the period of the formation and elongation of the vegetative shoots (which will later bear the buds). Consequently, the day temperature should be raised to 30°C and the night temperature to 15°C for a few days immediately after pruning and then lowered respectively to 25°C and 12°C for the 20 days preceding harvesting. This operation improves the quality and allows production to start 60 days after pruning.

Photosynthesis is inefficient unless there is a constant relation between air temperature and humidity, especially when the weather is hot. For a short period just after pruning, the humidity must be high in order to stimulate bud formation and development (85 to 90%). After a time, and until 30 days before harvesting, it should be maintained at 70-75% before finally being lowered to 60% until the end of the cycle.

Light is a major factor for rose production, and it must not be overlooked when selecting a greenhouse and its location as well as when deciding to shade in order to limit thermal excess - IR radiation - because it also reduces photosynthetically active radiation.

A2. Soil

The rose is a tolerant plant as far as soil is concerned, although it grows better in a reasonably heavy soil than in a very light one. Good drainage is essential.

B. Varieties and rootstocks

B.1 Desirable characteristics of varieties

Proper selection of the varieties to be grown is an essential condition if good economic results are to be obtained. The varieties should have the following characteristics :

- high yield and quality;
- good compatibility with the rootstock;

- low temperature requirements for Mediterranean winter production;
- regular-shaped flowers with more than 35 petals;
- rigid flower stalk;
- pure, strong colour and some scent;
- abundant foliage;
- vigour and easy propagation;
- short period from pruning to flowering;
- pest and disease resistance;
- packing and shipping resistance;
- long postharvest life.

Not all these features can be found together in any one variety. For this reason some 30 varieties are grown and account for 90% of the current production.

Cultivation and breeding have been oriented for some years towards varieties with improved winter yields and medium length stems instead of the traditional long ones, since it is desirable to increase the number of blooms per unit area, even at the expense of stem length.

The varieties grown for cut-flower production belong in general to the hybrid tea or grandiflora groups.

Long-stalk varieties :

Visa (R), Lovita (R), Baccara (R), Red Success (R), Alfa (R), Ilona (R) Chamade (R), Vega (R), Samantha (R), Lara (RC), Omega (RC), White Success (W), Cocktail (Y), etc.

Medium-stalk varieties :

Mercedes (R), Bingo (R), Sonia (RC), Carinella (RC), Carina (RC), Carte Blanche (W), Banzai k (Y), etc.

Foribunda varieties (small-sized plants, producing a succession of flowers) :

Garnette (R), Garnette Orange (RC), Zorina (OC), Carole (RC), Blanca Nieves (W), Bonica (W), Evergold (Y), etc.

(R red; RC rose-coloured; W white; Y yellow; OC orange-coloured)

Nowadays, the most popular rose cultivars in the Mediterranean regions are:

- Sonia: Portugal, Spain, France, Italy, Greece, Cyprus, Lebanon, Tunisia, Morocco ...;

- Baccara : France, Italy, Greece, Cyprus,...

Desirable characteristics of rootstocks

Rootstocks should have as many as possible of the following characters:

- compatibility with the commercial varieties grown;
- good health and vigour
- beneficial effect on yield and quality;
- a minimum productive life of 6 to 8 years;
- resistance to low temperatures, and a positive effect on winter production;

- good nutrient uptake and adaptibility to different soils;
- soil pest resistance;
- powdery mildew resistance;
- minimum thorn development;

R. indica major and R. manetti rootstocks are generally used in Mediterranean countries. They are propagated by woody cuttings. Since they are sensitive to low temperatures, they are unsuitable for cold countries, where seed-propagated rootstocks of the group R. canina are preferred.

R. indica major is a good rootstock for greenhouse cultivation. Its spread has been delayed due to powdery mildew sensitivity, which is a serious problem for nursery production, and also due to incompatibility with some commercial varieties. It performs well in soils of pH 5-8 and develops a large root system that withstands variations in water supply.

R. manetti is also a very good rootstock for winter forcing; it is compatible with most commercial varieties. Root development is fine, more shallow than that of R. indica, and so is well adapted to shallow soil conditions. It is not so tolerant to different soils, and performs better in the well aerated ones.

C. Cultural practices

C1. Growing period and cycle

The rose plant is kept in cultivation for 5 to 8 years. The flowering rhythm pattern varies with varieties. In general, flowering is discontinuous, a new cycle beginning every 6 to 8 weeks depending on the season. Consequently, to achieve continuity in greenhouse production, it is advisable to delay or advance some plots by combining varieties properly and by regulating the temperature.

C2. Soil preparation

The soil is ploughed 60 cm deep at the end of summer and the organic matter (8 to 18 kg of manure per m², or 3 to 5 kg of peat with the balance of the application made up by manure) is worked in together with the base dressing (maximum 0.25 kg of K_2O and 0.10 kg of P_2O_5 per m²). All this is followed by a sterilization treatment.

C3. Transplanting

Planting is done between November and February. The plants removed from the cold chamber are left in their closed packages for a few days so as to develop new roots before being treated with rooting agents and fungicides. The long and poor roots are then cut and the plants are set out in a moist soil. It is essential to avoid dehydration during and after planting. Low tunnels help to reduce transpiration losses until new roots have developed. Anti-transpirant sprays can be useful as well. Two or three branches, pruned to a minimum of two buds, are retained.

The recommended planting density is 7 to 8 plants per m². Plants are established 0.20 m apart each way in double rows separated by wide paths (1.20 m).

The plants are covered with soil up to a few cm above the graft point at planting and, when they are well rooted, the soil is removed and the graft point is left at soil surface.

The new branches are pinched when green to 3-4 leaves, in order to build a good frame. The weak shoots are removed. Mild temperatures - 13 to 16°C at night - are recommended at this stage.

C4. Pruning

The rose plant needs a vegetative rest period to accumulate reserves before pruning. Harvesting is stopped, watering and fertilizing are continued as before until a heavy canopy has developed. Watering and fertilizing are then stopped to allow the reserves to be translocated down to the woody stems.

C4.1 Pruning in a cold greenhouse

Winter pruning. Done during January. It consists of:

- cutting at 60-100 cm, depending upon the vigour of the plant and on the growing system;
- removing the dry and weak branches, and thinning out in cases of excess density or of small diameter. A branch segment with two leaves of 5 to 7 leaflets is left on the plant at harvest.

Summer pruning. The operations are performed in August or early September, depending on when harvest is scheduled to start : in autumn and after a 6 to 8-week rest.

- The branches are cut 20-30 cm above the winter cutting points. The lower weak branches are kept when they do not disturb the operations, in order to maintain as much leaf area as possible in anticipation of the reduction of light in autumn.
- Thinning out is performed where the growth is too dense and where the stem diameter is less than that of a pencil.

C4.2 Pruning in a heated greenhouse

Since the harvesting cycle is not interrupted during wintertime, pruning is limited to the summer operations, which are performed after a rest period. Two basic theories govern the operations but the methods vary greatly.

1. Cutting at a length of 80-90 cm on wood formed in the previous season and eliminating the weak branches. The production is obtained on the new branches.
2. Cutting at 60-70 cm and pinching the resulting growth to 4-7 leaves 3 weeks later. The need to pinch further is determined by the date of pruning and by the date the first harvest is scheduled. If new pinchings are required, 6 to 7 leaves must be left. These operations delay the flowering by 25 to 40 days, depending on the season, and increase the length and diameter of the branches. From the 3rd or 4th harvest, the stalks can be cut below the preceding cut, providing it is convenient to keep or improve the plant structure.

   The time for this pruning (b) depends on the method of pruning chosen and the first harvest schedule. It is normally done in June or July.

C5. Fertilization

Top dressing can be summarized in the following table :

	N	P_2O_5	K_2O
Soil content (ppm) in aqueous soil extract 1:5	130–200	40–80	200–350
Fertilization (g/m²/year)	200–100	50–30	150–100

N.B. The amounts of fertilizer depend mainly on the uptake by the crop. The aqueous soil extract is a means of regulating the nutrient supply but does not allow calculation of the total fertilizer requirement (see §5.2). This table is given as a general indication.

Soluble nutrients are very frequently supplied by means of low sprinkling, drip or other localized irrigation systems. Foliar fertilizer sprays are also useful (two applications in ten days from the time the shoots are more than 15 cm long). This prevents trace element deficiencies and also stimulates vegetative growth.

C6. Harvesting and marketing

The distance to, and the requirements of the market as well as the varieties determine the degree of opening that the flowers must have reached at harvest time. The stalks are expected to be as long as possible but two or three buds are to be left on the plant. The roses are harvested when solar radiation is at its lowest; the imperfect flowers are eliminated and the rest are graded according to the length of the stalks : extra : over 90 cm; first : 80-90 cm; second : 70-80 cm; third : 50-70 cm.

The bottom 20 cm of the stalks are stripped of thorns and leaves and the flowers are packed in batches of 20, 40 or 60, using boxes 60-100 cm long, 22-50 cm wide and 9-10 cm tall. It is advisable to keep the flowers at 4°C for some 4 hours before handling.

C7. Potential yields

For an established crop with a range of varieties, 180 to 220 flowers per sq. m per year is an average yield for short-stalk cultivars and 150 to 180 flowers for long-stalk cultivars: the longer the stalk, the smaller the yield per sq. m.

D. Major pests and diseases

The most frequent pathological troubles for the rose plant are:

Fungi: powdery mildew (*Sphaerotheca pannosa*); downy mildew (*Peronospora sparsa*); black spot (*Diplocarpon rosae*); rust (*Phragmidium mucronatum*); Botrytis blight (*B. cinerea*)...
Arthropods: *Aphids*; *thrips*; spider mite (*Tetranychus urticae*)...
Nematodes: *Meloidogyne incognita*; *M. hapla*; *Pratylenchus vulnus*; *Trichodorus christiei*...
Viruses: rose mosaic virus (not common)
Bacteria: crown gall (*Erwinia tumefaciens*) ...

E. Economics

The cost distribution can vary widely, depending on the type of crop and on the installations. A general distribution for a cold crop in a rigid polyester greenhouse (Spain), is :

- basic materials (plants, fertilizers, pesticides, etc.) : 17%
- labour : 37%
- installations and equipment amortization : 30%
- other costs (insurance, taxes, interest, etc.) : 16%

F. Major restraints

The main difficulties are :

- the lack of trained people having a good technical background to conduct a successful crop and able to manage an enterprise;
- the high risk due to the major investments needed in plant material and installations;
- in some areas, the lack of marketing organizations and structures;
- the present dwindling of the family-sized farms.

6.2.2.3 POT PLANTS

Most Mediterranean countries have a long tradition of decoration based on pot plants, which means that there exists an important potential local market in addition to the foreign outlets.

A. Cultural practices

The different types of climate prevailing in the Mediterranean region and the manifold requirements of pot plants provide a great number of openings. Minimum costs, high quality plants and simple installations are the three ideal components. The frost-free regions are of course particularly recommended.

A1. Open-air cultivation

Some pot plants can be grown in open-air cultivation. For instance, Ficus elastica for the production of cuttings; palm-trees such as Phoenix canariensis, Washingtonia filifera as well as many succulent plants and cacti, Aloes, Euphorbias, etc., are well adapted.

A2. Simple installations

The nets (shades) that keep off part of the light and are particularly useful in wind-free regions are a type of simple installation. They are used for plants that need shade and that are fairly insensitive to cold, e.g. many cactaceae (Zygocactus, Schlumbergera, Epiphyllium, etc.), Aralia japonica, Hedera, Asparagus, Aspidistra and many others that cannot possibly be listed here since their cultivation in a given region is subject to the outside climatic conditions. The nets reduce light and, during the winter nights, when there is no wind, the temperatures under these shades are just a few degrees higher than outside. The soil temperature is 3-4°C lower than outside. In summer, the day temperatures under the shade are lower, which proves advantageous.

A3. Greenhouses

The high costs involved for such crops may certainly justify investment in more expensive structures, covered with glass and fitted with classic heating and cooling systems. These installations are more profitable around cities when the climate is unfavourable or when special plants are cultivated.

Plastic-covered greenhouses are also useful, but they may cause important fluctuations in temperature and in humidity during the day and these have to be tempered by means of double films and/or the application of white paint on the outer surface. Here too, the type of plants that can be cultivated is determined by the outside climate. If there is no risk of frost, Sansevieria, Ficus (benjamina, elastica, lyrata), Ananas, Schefflera, Philodendron, etc. can be grown.

A special type of greenhouse is the "Insole" or buried greenhouse (Fig. 98), particular to the region of Almeria. It has a high degree of thermal inertia, which makes it suitable for the cultivation of heat-demanding plants, and does not require the addition of heating in winter (Dieffenbachia, Coediaeum, etc.).

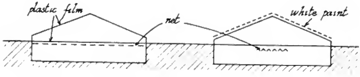

Fig. 98: Buried greenhouse ("insole") used in Spain.

In winter, a net stretched inside the greenhouse keeps off the excess of light while, in summer, the same result is obtained with a layer of white paint applied to the upper film.

B. Substrates, pots and fertilization

The use of local materials is to be encouraged (bark, pine needles, volcanic soil), but each one deserves particular consideration. The substrate must be light and well aerated, withhold water and nutrients and be free of weeds and of toxic products. If no such materials are available, a mixture of peat and fine sand in the ratio of 3 to 1, or sometimes peat alone, will do. But substrates such as these must be enriched with 0 to 2 g of $CaCO_3$ per litre and with 1 to 3 g of a compound fertilizer (e.g. N-P-K-Mg/10-5-12-3) according to the type of plant cultivated.

In general, the green plants that do not produce flowers need more nitrogen while the plants with flowers or coloured foliage need more potassium. Fertilizers are supplied in the irrigation water or sprayed on to the leaves; the ratio is 1 to 3 g/l water.

Plastic pots are increasingly popular in the commercial production of pot plants because they are lighter and more resistant. The holes at the bottom of the pot must remain unobstructed because water must not be permitted to collect in them. If the plants are grown in an unheated shelter, watering needs particular attention to prevent water excess.

C. Ecological requirements

The **light** requirements are relatively low (between 2 000 and 10 000 lux) and, therefore, light must not be allowed to reach an excessive level.

Even if problems may arise because of inadequate temperatures, it must be kept in mind that excessive temperatures are a greater threat, hence the need to apply a layer of white paint to the cover in summer and to wash it away in winter, if necessary.

The quality of **water** is of paramount importance. Indeed, ornamental plants are quite sensitive to salinity and they are put at risk when the water contains too much calcium carbonate (it causes whitish spots on the leaves). To avoid problems, it is best to keep between 0.6 and 1 millimhos/cm at 25°C.

D. Propagation

It is impossible to describe here all the methods in detail because of the large number of plants cultivated in pots, but a basic principle is to be observed: the plant material used must be healthy and be discarded if doubtful.

Some plants can be multiplied by sowing (Palm-trees, some Bromeliaceae, Asparagus, Scheffleras ...); others (Sansevieria) are propagated by **division**; for the majority, **cuttings** are used. Cuttings often need heat to form roots, and therefore propagation operations should take place in summer if specific installations are not available. Tissue culture (micropropagation) is becoming a frequent method of multiplication of ornamental plants.

E. Major restraints

As a conclusion, the production of ornamental plants in the Mediterranean region may be considered as an interesting activity but:

- new techniques should be developed that would suit its conditions of production;
- local industries should be created to provide the materials needed in this field: plastic pots, treatment products, plastic films, substrates, ...
- until some enterprises specialized in the production of plantlets are created, import facilities should be granted to the farmers.

6.2.3 FRUITS

6.2.3.1 GRAPE-VINE (Vitis vinifera)

Protected cultivation of grape-vines is widespread in the southernmost regions of Italy and can be found in some other regions such as Portugal and Spain.

Its main objectives are:

- to advance maturity of the bunches (June) of some early varieties;
- to protect some late varieties from unfavourable atmospheric factors (rain, wind, hail) and thus to delay the harvest time until December.

The first goal can be achieved under plastic houses or under simpler shelters which cover individual rows of vines. The cover is to remain from bunch formation (February, March) up to bunch maturity. The Cardinal variety is the most widely grown in Italy under protected cultivation. It gives a better quality production, earlier ripening (about one month), which is the most important feature, and sometimes higher yields (10 to 20% more than in the open air). In fact, higher yields can be the consequence of better irrigation, higher fertilization, longer pruning, higher plant density, used in protected cultivation.

The problems of the vine in protected cultivation are related to:

- **ventilation of the greenhouse**, to avoid high temperatures (above 30°C) and high air humidity levels : therefore, the shelters are sometimes only formed by a top cover and a lateral windbreak (prevailing winds);
- **control of diseases**, particularly fungi and Botrytis;
- **cultivars**: the "Italia" variety, which shows some tolerance to Botrytis and, to a lesser extent, the "Regina" cv are to be recommended. But it is the "Cardinal" cv that seems most suitable for Portugal, Greece and Cyprus ...
- **methods of water distribution**, to avoid an increase in humidity level; drip methods are the most suitable.

PE or EVA films are used in Italy; they must be stretched before the rains (end of August) and until the harvest (November-December). Only the upper part of the structures is covered, while the sides and some spaces between the rows are free, to allow bunch ventilation and lighting. The cover can be fixed on the structures installed for the training and trimming of the vines. Botrytis and other fungal diseases of the fruit require special control when the air humidity increases.

In Portugal, polypropylene nets are used, both on the roof and on the side walls. Waterproof covers are not required, because grapes have leaves only from March onwards and only for part of the year, and rainfall is low. A P.P. textile, being a little porous, allows some ventilation, reduces condensation and is more resistant to tearing than PE or EVA films. The results are very good.

6.2.3.2 BANANA (Musa ensete)

Some favoured regions of the Mediterranean zone have been producing bananas **in the open** for many years (about 175 ha in Crete).

The economic crisis that has been afflicting the world recently has led some countries to attempt cultivation **under shelter**: a few acres are being devoted to banana cultivation in **Portugal**; in 1983, there were about 60 ha in Crete and this figure is increasing by 15 to 20% every year; **Morocco** is recording an upsurge (80 ha in 1984 followed by a steady progression since then) such that some regard it as a sure way to self-sufficiency.

A. General description

A1. Plant

The banana is a herbaceous plant with a rather short underground stem (rhizome or stump) likely to develop suckers that will assure perenniality. The leaf sheaths slightly overlap each other to form the trunk. The plant bears about 30 leaves whose rate of development depends on the climatic conditions.

A2. Inflorescence

After the apical bud has initiated, it develops into an inflorescence borne on a stem which originates inside the trunk and slowly emerges out of the sheaths and out of the leaf stalks.

All the way up the axis of the inflorescence there appears a series of bracts, each of them covering a group of bare flowers arranged along two rows and overlapping each other.

The first 5 to 15 flower groups are exclusively **female** (= "clusters"). The following groups develop later and bear staminate flowers, often without pollen. Once the inflorescence emerges out of the trunk it bends downwards but the terminal remains active. The bright-coloured spathes rise in succession to show the various "clusters" constituting the bunch. Then the young fruits turn upwards and the bunch takes a position opposite to the one seen on the market. The bunches are picked when they have reached a certain weight though the bananas are still green (see Fig. 99).

B. Ecological requirements

Native to humid and warm tropical regions, the banana-tree has particular climatic requirements that have to be strictly kept to.

B1. Insolation

The banana-tree requires quite strong insolation, of the intertropical type, thus easily achieved in the Mediterranean countries. It seems insensitive to photoperiod.

B2. Temperature

Below 16°C, the meristem becomes dormant. When temperatures do not reach 20°C, new leaves develop more slowly. The plant does not seem to tolerate temperatures below 12°C without serious risk of damage. The optimum mean temperature would range from 25 to 30°C.

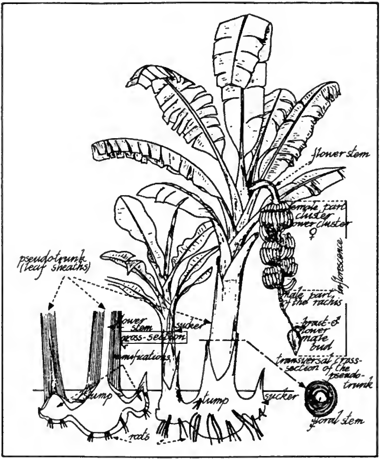

Fig. 99: Schematic view of a fruiting banana-tree and of its suckers (from CHAMPION J., "Le Bananier", Maison Neuve et Larose, Paris)

B3. Water

Just as for any tropical plant, the water requirement is high and constant. The tree is sensitive to drought : in the event of water shortage, the leaves wilt, the sheaths wither and the trunk breaks. Fortunately, the stump is much more resistant than the epigeal part and can withstand long periods of drought. It is generally agreed that, in favourable conditions, a banana-tree develops one leaf per week, that the surface of a leaf is about 1 m^2 and that the plant produces an average of 15 functional leaves. The total leaf surface ranges about 15 m^2, which means that LAI is about 4. ETP per plant would consequently average 25 l on a sunny day, i.e. 6 l/m^2 of ground, which corresponds to monthly rainfalls of 100-150 mm according to insolation.

B4. Wind

Everybody knows the lacerating effects of the wind on the leaves of banana-trees cultivated in the open.

B5. Soil

Light soils are required, due to the weakness of the root system. Hardened horizons are to be avoided as they would hamper the spread of the roots. On the other hand, the roots do not tolerate stagnant water (the water table should be at a depth of at least 1 m). Optimum pH is 6 to 7.5.

C. Cultural practices

C1. Soil preparation

The need for deep tilling and for draining before planting depends on the nature of the soil and the level of the water table.

C2. Planting

Various types of vegetable material can be used provided they bear at least one bud (apical or lateral). As a rule, a sucker is taken with part of a rhizome and a few roots (length of the sucker : 1 m). The planting density is, as already mentioned, 2 000 - 2 500 suckers per ha. The collar of the rhizome should ideally be about 10 cm above ground level and all the terminal buds of a given line should face in the same direction so as to be kept aligned and not to encroach on the spaces between the lines or on the paths.

Planting is carried out in greenhouses in the Mediterranean region so as to assure optimum climatic conditions for the various vegetative and generative stages of the banana-tree. As a rule, suckers are not allowed on parent plants until April or early May. The number of suckers produced after that time is high enough to create a new plantation or to reorganize the existing one.

C3. Offshooting (Pruning)

This operation proves unnecessary when the planting material is a central bud. When it originates from a lateral sucker, other suckers are to be eliminated to avoid nutritional competition. In Crete, it is common practice to keep three shoots per plant, the oldest being the first to produce fruits and an interval of 3 to 4 months being observed between any subsequent fruit production.

C4. Attention at the time of flowering

When the terminal bud develops at the top of the leaf rosette, the leaves have to be drawn aside or even cut so as to facilitate its way out. The inflorescence does not tolerate mechanical damage at fruit setting. Later on, the male part of the inflorescence should be removed (15 to 20 cm from the last cluster) as well as any cluster not likely to develop rapidly into good fruits.

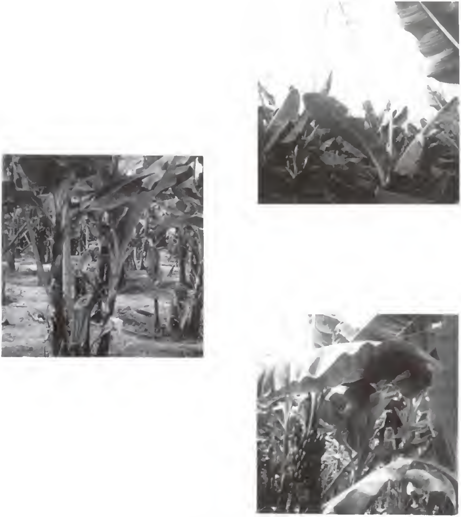

Fig. 100: Banana-tree at different stages (Parral greenhouse - Morocco)

C5. Thinning out

Old leaves are to be removed when dry (when hanging down along the trunk) so as to give access to every plant.

C6. Soil management

Soil management is of paramount importance, since the banana-tree is shallow-rooted and thus subject to competition from any kind of weed. The ground is often kept in a bare condition, which is easy when the banana plantation is not of recent creation (the leaves cast shade on the ground), but far less easy during the first weeks of planting and right after the first harvesting.

C7. Irrigation

In the Mediterranean region, the irrigation system remains traditional (furrow irrigation) but, in modern farms, sprinkler irrigation systems are used and provide suitable humidity in the greenhouse.

C8. Fertilization

One metric ton of medium-sized fruit removes from the soil 1 to 2 kg of N, 0.5 kg of P_2O_5, 5 to 7 kg of K_2O, 0.2 to 0.4 kg of CaO and 0.3 to 0.5 kg of MgO. These figures show that the banana-tree :

- requires substantial doses of K_2O, preferably applied in the form of sulphate rather than chloride;
- does not need large quantities of P_2O_5;
- requires well balanced nitrate fertilizing.

The average amounts commonly accepted per ha are :

- 1 500 kg of nitrate or of ammonium sulphate at the rate of 6 kg per irrigation;
- 2 000 kg of potassium sulphate, mainly before and during fruit-setting.

As a rule, the organic manure is sufficient to meet the phosphate requirements (between 50 and 100 T per ha).

C9. Varieties

The variety most commonly met now is the "Dwarf Cavendish", belonging to the group of the "Cavendish" or "sinensis". Its common name is "Small dwarf".

This variety yields somewhat less than the other dwarf ones but is grown more easily in greenhouses (max. height 5m instead of 6-6.5m for other cvs). The origin of the plants used is of prime importance; Morocco has selected clones which prove of the utmost interest, above all in the present conditions where micropropagation leads to the multiplication of any available material, whatever its origin and value.

D. Types of greenhouses

Multispan greenhouses or "mosque" ones are necessary to house the trees as well as to cover sufficient ground. The high-pitched "Parral" greenhouses that are up to 5 m tall exactly suit the cultivars grown in Morocco (Fig. 101). In Crete only the Dutch type of greenhouse has been erected until now (wooden framework, joined spans, plastic cover, average height 3m).

Ventilation requirements are reduced by the fact that, the greenhouse volume is important and the level of humidity outside the greenhouse is maintained at a high level, which is due to the high rate of evapotranspiration of the crop, the use of sprinkling irrigation and even complementary misting.

E. Pests and diseases

During the first years, the grower faces few phytosanitary problems. After some years, the damage caused by nematodes shows up (involving the use of nematocides) as well as that caused by red spiders (which leads the grower to cut back the plants severely every 9-10 months). For the time being, Fusarium is not likely to be fully controlled.

F. Ripening

Harvesting covers a long period and may reasonably be timed to meet the demand on the market.

The bunches are picked when still green and stored in a room maintained at constant temperature (16°C). The fruits begin to yellow some 3 days later. From this time, they start the keeping period, which is of 10 days at 15°C or for a longer time at lower temperatures.

6.2.3.3 PINEAPPLE (Ananas comosus L. Merr.)

This plant is native to South America but is now being cultivated in the Mediterranean regions because of the attractiveness of its fruits, eaten fresh or preserved.

It belongs to the family Bromeliaceae, most members of which are epiphytic. Even though the pineapple is a terrestrial plant, it has characteristics in common with the other members of the family and its rosette leaves form a "vase" through which water, nutrients and growth regulators can penetrate.

A. General description

It is an herbaceous perennial plant bearing long leaves around a short stalk. Some varieties have spiny-margined leaves. The fruit (infrutescence) develops from the inflorescence at the end of the stalk, and the well-known shape is the result of seedless fruitlets pressed together. It varies in colour from yellow to orange; to be fully flavoured, it must ripen on the plant.

B. Ecological requirements

The best growing conditions are a warm and moist climate, free from major variations throughout the year. If there is no risk of frost, the pineapple can be grown under shelter in the Mediterranean region and gives good quality fruits provided that certain precautions are taken.

Excessive temperatures may cause burns on the leaves and on the fruits. During periods of low temperature, excessive humidity is to be avoided both in the soil and on the plants. A light, slightly acid soil, rich in organic matter and providing an adequate water supply but no excess of water is desirable. The plant is fairly insensitive to wind except during the fructification period.

C. Varieties

Among the best known varieties are:

"Red Spanish", with pale yellow flesh, excellent for fresh consumption and resistant to transport;

"Smooth Cayenne", yellowish, perfect for canning;

"Natal Queen", golden yellow-fleshed, for fresh consumption and preserving well after ripening.

D. Cultural practices

D1. Propagation

The plant increases easily from natural suckers (Fig. 101).

The disadvantage associated with exclusive use of this material for propagation is that the plants are multiplied without taking into consideration the quality of the fruit. Consequently it is recommended, after careful selection, to remove the plants chosen for propagation, to strip them of their leaves and to cut up the stalks into pieces. These pieces of stem are then disinfected with a 2% solution of permanganate and planted in peat covered with sand in a sun-proof and moist place. A high temperature is needed constantly for rooting. Therefore, it may be necessary to heat the greenhouse (soil heating). The buds begin to form some 30 days later. Each stalk may produce up to 15 new plants.

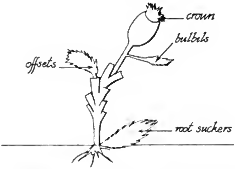

Fig. 101: Diagram of Ananas plant and of the various suckers it forms

D2. Planting

If the soil lacks organic matter, it is recommended to supply a 1/1 mixture of well decayed farm manure and of peat at the rate of 10 kg per m². One thousand kg of 8-3-16 fertilizer per ha is a satisfactory dressing. If the water supply lacks magnesium, it is advisable to provide some.

After planting, it is recommended that the leaves are sprayed with urea, ferrous and magnesium sulphates every 3 to 4 months, particularly during the warm season.

Weeds are not easy to control when the plants have developed fully; for this reason, black plastic mulching or sand mulching is advised.

The plants are spaced 40 cm apart, in twin rows 50 cm apart, leaving a 1.20 m path between the twin rows.

D3. Floral induction

Artificial induction of floral differentiation is common practice. Various products are used, but the best results are obtained with Ethrel (a solution of ethephon). The treatment in the "vase" of the plant is repeated 2 or 3 times, leaving a few days between each application.

D4. Harvesting

Quality fruits cannot be expected if harvesting takes place before the fruits are coloured. It is best to wait until the bottom part of the fruit turns orange. The exact time depends on the variety.

E. Major pests and diseases

With healthy plant material and a new soil the problems are reduced.

However, in case of doubt, it is recommended to immerse the propagation material in a solution of malathion/diazinon, because the main problem is caused by a scale insect difficult to control by classical treatments. Nematodes are also a risk and it is best to ensure that neither the propagation material nor the soil are contaminated.

F. Final note

The cultivation of pineapples may offer some interest for those countries that face import restrictions or when there is a demand for fresh fruits at a reasonable price.

6.2.3.4 PAPAYA (Carica papaya L.)

The papaya plant is native to Central America and has been introduced into all the warm climate countries around the world. It is attractive for its rapid growth and for its fruits rich in vitamins.

A. General description

The papaya "tree" is a herbaceous plant that can theoretically yield fruit for many years even if, in practice, production is limited to 3 or 4 years. When young, the tree has a single trunk, but with age, it branches and reaches 8 to 10 m high. The leaves are large and incised, and have a long petiole. When falling, they scar the trunk. It is a polygamous plant, bearing either hermaphrodite or unisexual (male or female) flowers on the same stem or a combination of them. This, of course, influences reproduction.

B. Ecological requirements

The papaya prefers warm and moist climates but it grows well in Mediterranean climates, assuming it is not exposed to frost. In summer it develops rapidly; under plastic, there are risks of scorch when the temperature rises too much. It is therefore during the warm season that its water and nutrient requirements are highest.

During the cooler season, in the Mediterranean regions, growth is slowed down and care must be taken to avoid excess water that could damage the roots. It does not require high quality water, which is a valuable advantage. Because of its large leaves, it is highly sensitive to wind and, therefore, is preferably cultivated under shelter. The papaya likes deep, fertile and well-drained soils.

C. Varieties

Propagation takes place mainly by seeds; the varieties are not fixed and vary. The best known "variety" is the Solo of Hawaii with its variants: Sols 5, Solo 8, Solo Kapone, Solo Sunrise, etc. Other cultivated varieties are Puna and, in Florida, Bluestem and Betty.

In the Mediterranean regions, the plant must not be allowed to grow too high and it has to produce medium-sized fruits with a colourful - preferably pink - flesh and high sugar content.

D. Cultural practices

D1. Propagation

Propagation is essentially by seeds. But various studies have shown that pistillate flowers fertilized by staminate ones produce an equal number of male and female plants; this is in fact an inconvenience since several plants have to be planted in the same hole and remain there together until blossoming, i.e. when the sexes can be distinguished and the surplus males eliminated. On the other hand, pistillate flowers pollinated by bisexual (hermaphrodite) ones produce an equal number of female and bisexual flowers. Bisexual flowers cross-pollinated produce one female plant for every two bisexual ones.

The last two cases are of course much more advantageous than the first. Cutting and grafting are also possible means of propagation but only with a view to safeguarding a particularly interesting plant.

D2. Planting

The roots go deep into the soil, which means that the soil must be dug thoroughly. It is recommended to work in 1 000 kg of calcium superphosphate, 500 kg of potassium sulphate and 50 000 kg of farm manure per ha. The plants should be spaced 2.5 m apart each way or 2 m one way and 3 m the other. The best time is late in the summer in order to keep growth within reasonable limits. Harvesting takes place 14 to 16 months later.

D3. Other management requirements

During the first year, each plant requires an additional 100 g of ammonium nitrate, 300 g of calcium superphosphate and 200 g of potassium sulphate. These quantities are doubled in the following year. The fertilizers (as well as water) are mainly to be supplied during the warm season.

D4. Harvesting

The fruits are harvested when they are about half coloured.

E. Major pests and diseases

The main problems in Mediterranean regions are caused by the red spider (Tetranychus sp.) and other mites that can be controlled by the application of sulphur and of other specific products. When new products are being tried great care should be exercised since the leaves are very sensitive and it is recommended to test on samples before any overall application, and to treat early in the morning or in the evening.

Oidium and Nematodes cause further problems.

In regions of extended cultivation, **viruses** can cause extensive damage, in particular **mosaics** and **ringspots**. When the papaya is cultivated under shelter, the best protection is offered by nets with fine meshes, especially treated to repulse aphids, which are the main vector.

F. General remark

The papaya tree is particularly attractive in the Mediterranean regions for its tasty and dietetic fruit and above all because it crops during the cool period, when hardly any other similar fruit is available on the market.

CHAPTER 7

ECONOMIC ASPECTS

Even if yields are not known, it is useful at least to know the cost price of crops protected under plastic in various Mediterranean regions.

Unfortunately, labour costs and major factors of production differ to a large extent from one country to another, and the techniques used vary greatly. Any comparison is, therefore, difficult to make.

Moreover, it is sometimes difficult to obtain complete economic evaluations of protected cultivation because some countries do not have enough information available.

Finally, cost prices are not fixed in the same way throughout the Mediterranean Basin. If one wishes to emphasize the relative importance of the various factors of cost price (rather than the cost price itself) as an absolute value, in order to avoid monetary equivalence, a standard evaluation procedure for production cost must be used for all the countries. This, however, goes against local customs and reduces the amount of information made available.

The following pages provide a number of evaluations which, in spite of their arbitrary layout, allow a certain number of comparisons to be made between countries.

The data are limited to tomatoes and peppers under plastic cover.

Of course, for greater accuracy, it would have been more interesting to insert these estimates in the context of more specific crop sequences. This, however, was not possible for the reasons mentioned above.

The following tables were drawn up by experts from the countries involved or established in an arbitrary way by adapting available information to a model layout for cost price as mentioned above.

Absolute values for these evaluations cannot be obtained from the results, in spite of similarities of cost price in the countries concerned. However, these results should give an idea of the impact of the major factors of production on production costs.

NB: In the following tables of figures, costs of the **greenhouse itself** have been separated from the plastic cover. Life span can be considered as in excess of 10 years for greenhouse construction but is 2 years or less for plastic sheets. The price for plastic sheets is included under "Materials" and installation costs for the sheets under "Labour" with the depreciation allowance taken into consideration. The greenhouse construction is generally included under "depreciation allowances for production materials". In any event, cost prices for the greenhouse framework vary considerably from one country to another.

Region: **CYPRUS** Crop: **TOMATO** Average yield: 13 kg/m^2

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	11.5		
Seeds-seedlings	3.75		
Manure-fertilizers	3.75		
Chemicals (pesticides, growth regulators)	4.80		
Irrigation water	1.7		
Miscellaneous	3.1		
Total "Materials"			28.6%
2. Labour			
Mechanical work		1.0%	
Manual work			
Greenhouse covering	1.4		
Chemicals application	2.8		
Training and pruning	8.5		
Harvest	28.2		
Maintenance of greenhouse & machinery	0.5		
Irrigation	2.8		
Miscellaneous	1.0		
Total manual work		45.0%	
Total labour			46.0%
3. Charges and duties			
Transport	6.6		
Brokerage	...		
Depreciation allowances and interests (including greenhouse structure)	18.4		
Miscellaneous	0.5		
Total charges and duties			25.5%
4. TOTAL	Total %		100%
	$ US (1.1.1986)		$5.3/m^2$
5. Cost price (for estimated yield 13 kg/m^2)	$ US		0.41$/kg

Region: **SPAIN** (South) Crop: **TOMATO** Average yield: 11.5 kg/m²

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	12.7		
Seeds-seedlings	4.0		
Manure-fertilizers	5.3		
Chemicals (pesticides, growth regulators)	12.0		
Irrigation water	-		
Miscellaneous	-		
Total "Materials"			34.0%
2. Labour			
Mechanical work		3.2%	
Manual work			
Greenhouse covering Chemicals application Training and pruning Harvest Maintenance of greenhouse & machinery	28.9		
Irrigation	7.8		
Miscellaneous			
Total manual work		36.7%	
Total labour			39.9%
3. Charges and duties			
Transport	-		
Brokerage	-		
Depreciation allowances and interests (including greenhouse structure)	26.1		
Miscellaneous	-		
Total charges and duties			26.1%
4. TOTAL	Total %		100%
	$ US (1.1.1986)		2.2$/m²
5. Cost price (for estimated yield 11.5 kg/m²)	$ US		0.19$/kg

Region: **SPAIN** (second estimate) Crop: **TOMATO** Average yield: 11.5 kg/m²

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	6.7		
Seeds-seedlings	2.8		
Manure-fertilizers	6.6		
Chemicals (pesticides, growth regulators)	13.0		
Irrigation water	1.5		
Miscellaneous	0.5		
Total "Materials"			31.1%
2. Labour			
Mechanical work		4.2%	
Manual work			
Greenhouse covering	3.5		
Chemicals application	7.0		
Training and pruning	9.8		
Harvest	17.0		
Maintenance of greenhouse & machinery	0.3		
Irrigation	0.1		
Miscellaneous	0.1		
Total manual work		38.9%	
Total labour			43.1%
3. Charges and duties			
Transport	1.1		
Brokerage	2.1		
Depreciation allowances and interests (including greenhouse structure)	21.7		
Miscellaneous	0.9		
Total charges and duties			25.8%
4. TOTAL	Total %		100%
	$ US (1.1.1986)		1.78$/m²
5. Cost price (for estimated yield 11.5 kg/m²)	$ US		0.16$/kg

Region: **FRANCE** Crop: **TOMATO** Average yield: 10 kg/m^2

	PRODUCTION COSTS	Percentage of total		
1.	Materials used			
	Film-cover	4.4		
	Seeds-seedlings	13.7		
	Manure-fertilizers	3.6		
	Chemicals (pesticides, growth regulators)	3.0		
	Irrigation water	-		
	Miscellaneous	1.2		
	Total "Materials"			25.9%
2.	Labour			
	Mechanical work		1.7%	
	Manual work			
	Greenhouse covering	-		
	Chemicals application	3.5		
	Training and pruning	19.5		
	Harvest	15.4		
	Maintenance of greenhouse & machinery			
	Irrigation	2.8		
	Miscellaneous	7.3		
	Total manual work		48.5%	
	Total labour			50.2%
3.	Charges and duties			
	Transport	-		
	Brokerage	-		
	Depreciation allowances and interests (including greenhouse structure)	23.9		
	Miscellaneous	-		
	Total charges and duties			23.9%
4.	TOTAL	Total %		100%
		$ US (1.1.1986)		4.56$/m^2
5.	Cost price (for estimated yield 10 kg/m^2	$ US		0.46$/kg

Region: **GREECE** Crop: **TOMATO** Average yield: 12 kg/m^2

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	9.6		
Seeds-seedlings	1.3		
Manure-fertilizers	1.9		
Chemicals (pesticides, growth regulators)	5.7		
Irrigation water	1.0		
Miscellaneous	1.8		
Total "Materials"			21.3%
2. Labour			
Mechanical work		1.0%	
Manual work			
Greenhouse covering	5.7		
Chemicals application	4.6		
Training and pruning	7.6		
Harvest	7.6		
Maintenance of greenhouse & machinery	3.8		
Irrigation	1.0		
Miscellaneous	4.7		
Total manual work		35.0%	
Total labour			36.0%
3. Charges and duties			
Transport	4.7		
Brokerage	–		
Depreciation allowances and interests (including greenhouse structure)	34.2		
Miscellaneous	3.8		
Total charges and duties			42.7%
4. TOTAL	Total %		100%
	$ US (1.1.1986)		3.9$/$\text{m}^2$
5. Cost price (for estimated yield 12 kg/m^2)	$ US		0.32 $/kg

Region: **ITALY** (Sicily) Crop: **TOMATO** Average yield: 11 kg/m^2

	PRODUCTION COSTS	Percentage of total		
1.	Materials used			
	Film-cover	7.1		
	Seeds-seedlings	2.0		
	Manure-fertilizers	6.3		
	Chemicals (pesticides, growth regulators)	6.8		
	Irrigation water	0.7		
	Miscellaneous	1.4		
	Total "Materials"			24.3%
2.	Labour			
	Mechanical work		6.1%	
	Manual work			
	Greenhouse covering	1.6		
	Chemicals application	3.8		
	Training and pruning	7.1		
	Harvest	13.5		
	Maintenance of greenhouse & machinery	2.3		
	Irrigation	1.5		
	Miscellaneous	1.4		
	Total manual work		31.2%	
	Total labour			37.3%
3.	Charges and duties			
	Transport	8.2		
	Brokerage	4.0		
	Depreciation allowances and interests (including greenhouse structure)	15.9		
	Miscellaneous	10.3		
	Total charges and duties			38.4%
4.	TOTAL	Total %		100%
		\$ US (1.1.1986)		3.7\$/m^2
5.	Cost price (for estimated yield 11 kg/m^2)	\$ US		0.33 \$/kg

Region: **SPAIN** Crop: **SWEET PEPPER** Average yield: 7.5 kg/m^2

	PRODUCTION COSTS	Percentage of total		
1.	Materials used			
	Film-cover	15.8		
	Seeds-seedlings	3.8		
	Manure-fertilizers	5.6		
	Chemicals (pesticides, growth regulators)	16.0		
	Irrigation water	-		
	Miscellaneous	-		
	Total "Materials"			41.2%
2.	Labour			
	Mechanical work		3.2%	
	Manual work			
	Greenhouse covering Chemicals application Training and pruning Harvest Maintenance of greenhouse & machinery	25.4		
	Irrigation	8.6		
	Miscellaneous	-		
	Total manual work		34.0%	
	Total labour			37.2%
3.	Charges and duties			
	Transport	-		
	Brokerage Depreciation allowances and interests (including greenhouse structure)	21.6		
	Miscellaneous	-		
	Total charges and duties			21.6%
4.	TOTAL	Total %		100%
		$ US (1.1.1986)		1.725/m^2
5.	Cost price (for estimated yield 7.5 kg/m^2)	$ US		0.23$/kg

Region: **SPAIN** (second estimate) Crop: **SWEET PEPPER** Average yield: 9 kg/m²

	PRODUCTION COSTS	Percentage of total		
1.	Materials used			
	Film-cover	8.7		
	Seeds-seedlings	2.0		
	Manure-fertilizers	7.9		
	Chemicals (pesticides, growth regulators)	8.7		
	Irrigation water	3.7		
	Miscellaneous	0.6		
	Total "Materials"			31.6%
2.	Labour			
	Mechanical work		5.5%	
	Manual work			
	Greenhouse covering	4.6		
	Chemicals application	3.8		
	Training and pruning	3.0		
	Harvest	12.5		
	Maintenance of greenhouse & machinery	0.4		
	Irrigation	1.8		
	Miscellaneous	6.4		
	Total manual work		32.5%	
	Total labour			38.0%
3.	Charges and duties			
	Transport	1.0		
	Brokerage	2.8		
	Depreciation allowances and interests (including greenhouse structure)	22.0		
	Miscellaneous	4.6		
	Total charges and duties			30.4%
4.	TOTAL	Total %		100%
		$ US (1.1.1986)		1.3$/m²
5.	Cost price (for estimated yield 9 kg/m²)	$ US		0.15$/kg

Region: **PORTUGAL** (Algarve)
Crop: **SWEET PEPPER**
Average yield: 6.0 kg/m²

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	6.8		
Seeds-seedlings	2.6		
Manure-fertilizers	12.0		
Chemicals (pesticides, growth regulators)	6.3		
Irrigation water	2.6		
Miscellaneous	1.7		
Total "Materials"			32.0%
2. Labour			
Mechanical work		8.0%	
Manual work			
Greenhouse covering	-		
Chemicals application	-		
Training and pruning	-		
Harvest	-		
Maintenance of greenhouse & machinery	-		
Irrigation	-		
Miscellaneous	-		
Total manual work		45.0%	
Total labour			53.0%
3. Charges and duties			
Transport	-		
Brokerage	3.0		
Depreciation allowances and interests (including greenhouse structure)	12.0		
Miscellaneous	-		
Total charges and duties			15.0%
4. TOTAL	%		100%
	$ US (1.1.1986)		2.2$/m²
5. Cost price (for estimated yield 6.0 kg/m²)	$ US	0.37$/kg	

Region: **TUNISIA** Crop: **SWEET PEPPER** Average yield: 4.0 kg/m²

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	24.4		
Seeds-seedlings	3.3		
Manure-fertilizers	2.0		
Chemicals (pesticides, growth regulators)	6.7		
Irrigation water	0.7		
Miscellaneous	2.1		
Total "Materials"			46.2%
2. Labour			
Mechanical work		1.4%	
Manual work			
Greenhouse covering	0.2		
Chemicals application	2.3		
Training and pruning	0.7		
Harvest	7.3		
Maintenance of greenhouse & machinery	8.8		
Irrigation	1.2		
Miscellaneous	-		
Total manual work		20.5%	
Total labour			21.9%
3. Charges and duties			
Transport	-		
Brokerage	-		
Depreciation allowances and interests (including greenhouse structure)	20.7		
Miscellaneous	11.2		
Total charges and duties			31.9%
4. TOTAL — Total %			100%
$ US (1.1.1986)			1.75$/m²
5. Cost price (for estimated yield 4.0 kg/m²) $ US			0.44$/kg

Region: **TUNISIA** Crop: **HOT PEPPER** Average yield: 2.6 kg/m^2

	PRODUCTION COSTS	Percentage of total		
1.	Materials used			
	Film-cover	32.4		
	Seeds-seedlings	0.1		
	Manure-fertilizers	5.7		
	Chemicals (pesticides, growth regulators)	0.9		
	Irrigation water	0.6		
	Miscellaneous	-		
	Total "Materials"			39.7%
2.	Labour			
	Mechanical work		5.2%	
	Manual work			
	Greenhouse covering	-		
	Chemicals application	-		
	Training and pruning	-		
	Harvest	-		
	Maintenance of greenhouse & machinery	-		
	Irrigation	-		
	Miscellaneous	-		
	Total manual work		11.5%	
	Total labour			16.7%
3.	Charges and duties			
	Transport	-		
	Brokerage	-		
	Depreciation allowances and interests (including greenhouse structure)	41.4%		
	Miscellaneous	2.2		
	Total charges and duties			43.6%
4.	TOTAL	Total %		100%
		$ US (1.1.1986)		1.74$/m^2
5.	Cost price (for estimated yield 2.6 kg/m^2)	$ US		0.67$/kg

Region: **TURKEY** Crop: **PEPPER (SWEET)** Average yield: 4.0 kg/m²

	PRODUCTION COSTS	Percentage of total		
1.	Materials used			
	Film-cover	27.3		
	Seeds-seedlings	1.3		
	Manure-fertilizers	20.0		
	Chemicals (pesticides, growth regulators)	8.1		
	Irrigation water	-		
	Miscellaneous	2.9		
	Total "Materials"			59.5%
2.	Labour			
	Mechanical work		0.9%	
	Manual work			
	Greenhouse covering	1.3		
	Chemicals application	1.3		
	Training and pruning	0.6		
	Harvest	6.2		
	Maintenance of greenhouse & machinery	1.6		
	Irrigation	2.5		
	Miscellaneous	1.1		
	Total manual work		14.6%	
	Total labour			15.5%
3.	Charges and duties			
	Transport	1.6		
	Brokerage	11.7		
	Depreciation allowances and interests (including greenhouse structure)	11.7		
	Miscellaneous	-		
	Total charges and duties			25.0%
4.	TOTAL	Total %		100%
		$ US (1.1.1986)		2$/m²
5.	Cost price (for estimated yield 4 kg/m²)	$ US		0.50$/kg

Region: **FRANCE** Crop: **EGG-PLANT** Average yield: 5 kg/m²

PRODUCTION COSTS	Percentage of total		
1. Materials used			
Film-cover	7.0		
Seeds-seedlings	13.8		
Manure-fertilizers	3.0		
Chemicals (pesticides, growth regulators)	1.6		
Irrigation water	-		
Miscellaneous	1.6		
Total "Materials"			27.0%
2. Labour			
Mechanical work		2.0%	
Manual work			
Greenhouse covering	15.0		
Chemicals application	-		
Training and pruning	4.6		
Harvest	14.4		
Maintenance of greenhouse & machinery	-		
Irrigation	-		
Miscellaneous	2.0		
Total manual work		36.0%	
Total labour			38.0%
3. Charges and duties			
Transport	-		
Brokerage	-		
Depreciation allowances and interests (including greenhouse structure)	35.0		
Miscellaneous	-		
Total charges and duties			35.0%
4. TOTAL	Total %		100%
	$ US (1.1.1986)		2.8$/m²
5. Cost price (for estimated yield 5 kg/m²)	$ US		0.56$/kg

CHAPTER 8

CONCLUSIONS

The subject dealt with here is too vast to be analyzed exhaustively.

The editor's main aim has been to offer the reader the most important elements of protected cultivation in its particularities in the Mediterranean region.

Each chapter, each paragraph could obviously be amplified a great deal more. Each author, specialized in the fields he has been treating here, can provide a large number of additional details. The latter can however probably be found in scientific and advisory publications.

The coordinator has tried to gather in a book of acceptable dimensions the following elements:

- the basic principles of protected cultivation in the Mediterranean region;
- the results of the chief experiments conducted so far;
- the present-day trend in some advanced fields;
- the present and future possibilities and limits of the techniques of protected cultivation in that region of the globe.

Therefore, the statistics of appraising protected cultivation in the Mediterranean region have been kept within strict limits. Similarly, and considering the great variety of sociological, economic and climatic features observed in the different countries constituting the so-called Mediterranean region, only the general principles of the subjects treated have been derived from the experience gained in those Mediterranean countries where protected cultivation is more advanced. Techniques whose suitability is strictly limited to northern countries and which are not likely to be exploited in the near future in the Mediterranean region have intentionally been ignored.

This book should encourage some improvement of the techniques applied in the countries recently converted to protected cultivation, thanks to the experience gained over the last two decades in countries enjoying much the same climate but with a somewhat different socio-economic context.

Intensification of the spread of protected cultivation techniques throughout the countries newly involved in protected cultivation should be facilitated and accelerated by the extension programme developed by FAO concurrently with publication of the present document and thanks to the help of members of the Draft Committee acting in their capacity as experts.

BIBLIOGRAPHY

Throughout this work, the reader will find footnotes which relate to a number of specific biographical references (backing up various ideas and themes developed).

The following is a more general list of works which provide a wider knowledge and a deeper understanding of the topics studied in this present work.

1. ANON **Fertilisation des cultures légumières.** C.T.I.F.L. - Paris

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ANNEX

MEMBERS OF THE WORKING GROUP

Ir. W. BAUDOIN
Crop Production Agronomist - Plant Production and Protection Division
FAO, C760
via delle Terme di Caracalla
I.- 00100 ROME (Italy)

Prof. M. GRAFIADELLIS
Agricultural Centre of Northern Greece
P.O. Box 54110
G.- 10514 THESSALONIKI (Greece)

Ir. R. JIMENEZ
Estacion de Investigacion sobre cultivos horticolas
Intensivos "La Majonera"
Carretera Nacional m.340 Km 90
E.- ALMERIA (Spain)

Prof. G. LA MALFA
Instituto di Orticoltura e Floricoltura
via Val di Savoia, 5
I.- 95123 CATANIA (Italy)

Dr. Ir. P.F. MARTINEZ-GARCIA
Instituto Valenciano de Investigaciones Agrarias (IVIA)
Apartado Oficial - La Alberca
E. - 46071 MONCADA. VALENCIA (Spain)

Prof. A.A. MONTEIRO
Instituto Superior de Agronomia
Tapada da Ajuda, 1399
P.- LISBOA (Portugal) codex

Prof. Dr. Ir. A. NISEN
Faculté des Sciences Agronomiques de l'Etat
Chaire des Cultures Fruitières et Maraichères
Avenue de la Faculté d'Agronomie, 2
B.- 5800 GEMBLOUX (Belgium)

Prof. H. VERLODT
Institut National Agronomique de Tunisie (INAT)
Avenue Charles Nicolle, 13
TN - 1002 TUNIS (Tunisia)

Ir. O. de VILLELE
Station de Bioclimatologie (INRA)
Domaine St. Paul
F. - 84140 MONTFAVET (France)

Prof. Ch. VON ZABELTITZ
Institut für Technik in Gartenbau der Universität Hannover
Herrenhaüser Str., 2
D.- 3000 HANNOVER 2 (Germany)

J.C. GARNAUD
Comité International des Plastiques en Agriculture
65, rue de Prony
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